Department of Geodetic Science

BASIC RESEARCH AND DATA ANALYSIS FOR THE NATIONAL GEODETIC SATELLITE PROGRAM AND FOR THE EARTH AND OCEAN PHYSICS APPLICATIONS PROGRAM

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PREFACE

This project is under the supervision of Professor Ivan I. Mueller, Department of Geodetic Science, The Ohio State University, and it is under the technical direction of Mr. James P. Murphy, Special Programs, Office of Applications, NASA Headquarters, Washington, D. C. The contract is administered by the Office of University Affairs, NASA, Washington, D. C. 20546

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1. STATEMENT OF WORK

The statement of work for this project includes data analysis and supporting research in connection with the following broad objectives:

(1) Provide a precise and accurate geometric description of the earth's surface.

(2) Provide a precise and accurate mathematical description of the earth's gravitational field.

(3) Determine time variations of the geometry of the ocean surface, the solid earth, the gravity field, and other geophysical parameters.

2. ACTIVITIES RELATED TO THE NGSP
(Grant No. NGL 36-008-093)

2.1 OSU 275 Set of Tracking Stations Coordinates and Transformations Parameters

The OSU 275 set of tracking station coordinates are based on the previously published WN 14 geometric solution for 158 stations (see Dept. of Geodetic Science Report No. 199), to which 117 stations were added either by direct survey connections (C) or by transformations (T).

The coordinate system in which the coordinates are presented is oriented towards the Greenwich Mean Astronomical Meridian (u axis) and the Conventional International Origin (w axis), both as defined by the Bureau International de l'Heure. The v axis forms a right-handed system with the u and w, and with u defines the average geodetic equator. The coordinates of the origin with respect to the geocenter are suggested to be

$$u_o = 17 \text{ m}, \quad v_o = 13 \text{ m}, \quad w_o = -1 \text{ m}.$$

The scale in the solution is defined through SECOR observations and weighted height constraints. Chord distances derived from C band radar observations and from electronic distance measurements (geodimeter and tellurometer) are also included as weighted constraints, but they seem to have very little or no effect.

The standard deviations for the "C" and "T" stations are estimated values. (See Table 2.1-1).

The results in respect of relationship between OSU 275 and various world datums and global dynamic solutions are given in Tables 2.1-2 and 2.1-3 respectively.

TRACKING STATION COORDINATES (SET:OSU275)

NO.		NAME	U	V	W	σ_u	σ_v	σ_w
80	C	SANFRNDO	5105601.7	-555293.7	3769644.7	5.0	12.0	6.0
1021		BLOSOMPT	1118023.1	-4876323.4	3942963.9	2.8	2.6	2.8
1022		FORTMYRS	807851.9	-5651989.6	2833500.2	2.2	1.9	2.3
1024	C	WOMRAUST	-3977293.6	3725625.1	-3302936.6	8.0	8.0	9.0
1025	C	QUITOECR	1263619.8	-6254990.6	-68890.1	5.0	5.0	6.0
1028	T	SANTIAGO	1769701.1	-5044622.9	-3468258.5	26.0	26.0	26.0
1030		MOJAVARZ	-2357242.9	-4646338.5	3668306.8	5.6	3.3	3.2
1031	C	JONSBURG	5084771.1	2670396.9	-2768146.7	5.0	5.0	6.0
1032		NEWFLAND	2602688.6	-3419228.9	4697637.3	39.3	46.7	13.3
1033		FAIRBNKS	-2299282.6	-1445693.7	5751811.6	6.9	9.7	5.7
1034		GRNDFRKS	-521704.5	-4242064.3	4718716.8	3.1	3.0	2.7
1035	T	WINKFILD	3983098.8	-48514.0	4964714.0	8.0	8.0	11.0
1036	T	FAIRBNKS	-2282362.1	-1452662.9	5756892.0	8.0	8.0	11.0
1037	C	ROSMANNC	647505.0	-5177934.9	3656705.5	4.0	4.0	5.0
1038	C	ORALAUST	-4447503.1	2677146.4	-3695065.0	8.0	5.0	5.0
1042		ROSMANNC	647497.5	-5177935.6	3656705.9	2.8	2.4	2.8
1043	T	TANARIVE	4091856.4	4434279.4	-2064728.7	9.0	9.0	9.0
1122	T	TANARIVE	4091206.0	4434257.1	-2066017.2	9.0	9.0	9.0
1123	T	TANARIVE	4091326.3	4434221.3	-2065973.7	9.0	9.0	9.0
1126	C	ROSMANNC	647171.1	-5178338.6	3656134.3	5.0	5.0	6.0
1128	T	FAIRBNKS	-2282517.6	-1453391.1	5756698.7	15.0	15.0	15.0
1152	C	CAVNAUST	-2328271.4	5299689.0	-2669355.6	5.0	11.0	16.0
2002	C	AUSTINTX	-741649.6	-5462247.2	3198081.2	6.0	5.0	7.0
2014	T	ANCORAGE	-2656190.3	-1544375.0	5570644.0	15.0	15.0	15.0
2017	C	TAFUNAAS	-6100020.7	-997208.5	-1568460.0	6.0	6.0	7.0
2018	C	THULEGRD	539377.6	-1388386.5	6181061.0	4.0	4.0	5.0
2019	C	MCMRDANT	-1310721.9	310448.9	-6213363.5	6.0	6.0	6.0
2020	T	MAHEILND	3602881.9	5238204.1	-515934.4	7.0	6.0	7.0
2049	T	PURTRICO	2440932.8	-5538065.9	2006220.8	5.0	5.0	5.0
2092	T	AUSTINTX	-741659.3	-5462215.8	3198133.2	5.0	5.0	5.0
2100	C	WAWHAWAI	-5504153.4	-2224161.2	2325298.3	5.0	6.0	5.0
2103	T	LASCRUCS	-1556231.4	-5169428.4	3387246.7	15.0	15.0	15.0
2106	T	LASAMENG	4005420.1	-71762.3	4946709.4	15.0	15.0	15.0
2111	T	HOWARDMD	1122633.1	-4823045.4	4006469.0	6.0	6.0	6.0
2115	C	PRETORIA	5051963.2	2725632.7	-2774463.8	5.0	5.0	6.0
2117	C	TAFUNAAS	-6100023.8	-997202.3	-1568461.9	5.0	5.0	6.0
2203	C	WALOPIND	1261662.0	-4881250.9	3893555.7	5.0	4.0	5.0
2707	C	DRWNAUST	-4071536.8	4714301.7	-1366474.1	5.0	5.0	6.0
2708	C	WAKEILND	-5858533.2	1394519.7	2093933.9	4.0	4.0	5.0
2709	T	PRTHAUST	-2377598.6	4889656.1	-3323432.3	34.0	28.0	36.0
2715	C	GAUMILND	-5064993.0	3582905.4	1475804.0	5.0	5.0	5.0
2717	C	MAHEILND	3602862.4	5238212.1	-515923.3	6.0	5.0	6.0
2722	C	ASCONIND	6118412.3	-1571576.3	-878436.0	4.0	4.0	5.0
2723	C	COCOSIND	-741998.7	6190792.2	-1338560.1	6.0	5.0	6.0
2724	C	MDWAYIND	-5619643.2	-256328.2	2995770.7	5.0	5.0	6.0
2726	C	MANUSAUS	-5367631.3	3437930.1	-226705.2	5.0	5.0	5.0
2727	C	TERCEIRA	4433585.5	-2268184.1	3971697.6	4.0	5.0	5.0
2735	C	STSTWART	832485.3	-5349594.9	3360533.6	6.0	5.0	6.0

(all units in meters)

Table 2.1-1

NO.	NAME	U	V	W			
2738 C	MOSESLKE	-2127836.2	-3785839.3	4656059.3	4.0	4.0	4.0
2739 C	SHMYAIND	-3851550.9	397259.4	5051470.4	5.0	5.0	6.0
2742 C	BLTVILMD	1130771.0	-4830825.8	3994718.5	4.0	4.0	4.0
2744 C	THRSILND	-4955422.5	3842218.0	-1163792.2	5.0	5.0	6.0
2745 T	STNVILLE	-85010.6	-5327963.0	3493447.7	6.0	6.0	6.0
2765 T	CHANGMAI	-941675.7	5967443.3	2039341.4	35.0	28.0	37.0
2766 T	WAKEILND	-5858540.6	1394520.9	2093920.5	34.0	28.0	36.0
2801 T	PALAUIND	-4433465.2	4512966.3	810002.7	35.0	28.0	37.0
2803 C	ROTASPAN	5093550.4	-565320.7	3784279.1	4.0	5.0	5.0
2805 C	CULGOORA	-4751646.9	2792064.7	-3200170.9	5.0	5.0	5.0
2809 C	INVRCRGL	-4313802.5	893029.2	-4596968.0	5.0	6.0	6.0
2811 C	MAUIHWAI	-5468016.8	-2381416.1	2253220.6	5.0	5.0	5.0
2812 C	CTNSICLY	4901577.8	1305816.5	3853648.4	4.0	4.0	4.0
2813 T	DAKARSNG	5884479.5	-1853566.1	1612735.8	5.0	5.0	5.0
2815 C	PARMARBO	3623258.4	-5214227.4	601519.1	4.0	4.0	5.0
2817 C	MSHDIRAN	2604345.4	4444161.8	3750336.7	4.0	4.0	4.0
2818 C	TRMSNRWY	2102936.3	721655.7	5958182.4	4.0	5.0	5.0
2820 T	VILDOLRS	2280571.4	-4914564.8	-3355440.7	8.0	8.0	8.0
2821 T	ZAMBONGA	-3361919.5	5365834.0	763659.0	7.0	6.0	7.0
2822 C	FORTLAMY	6023398.7	1617918.2	1331709.4	5.0	4.0	5.0
2823 T	CASEYANT	-902608.3	2409529.7	-5816541.2	7.0	6.0	7.0
2825 T	PAMERANT	1192559.3	-2451018.0	-5747057.2	7.0	6.0	7.0
2830 C	PISENBRG	4213528.3	820858.6	4702811.7	4.0	4.0	4.0
2831 C	SCROILND	-2160953.0	-5642737.8	2035332.5	4.0	5.0	6.0
2832 T	KSMJAPAN	-3417816.6	4115338.4	3461705.6	35.0	28.0	37.0
2837 C	NATALBZL	5186351.6	-3654224.1	-653024.9	4.0	4.0	4.0
2838 T	MAURTIUS	3223444.2	5045328.7	-2191792.0	7.0	6.0	7.0
2840 T	ADSABABA	4900753.9	3968227.8	966356.7	5.0	5.0	5.0
2844 T	QUITOECR	1280851.8	-6250961.6	-10839.8	5.0	5.0	5.0
2847 C	CERSMBRO	1371379.0	-3614768.6	-5055908.2	5.0	6.0	6.0
2849 C	XMASILND	-5885335.4	-2448384.7	221670.8	5.0	5.0	6.0
2907 C	CYPRSIND	4361707.6	2868048.6	3652828.0	4.0	5.0	5.0
3106	ATGUAIND	2881838.3	-5372164.6	1868538.6	3.7	3.3	4.3
3334	STNVILLE	-84963.8	-5327974.9	3493428.3	13.6	6.8	9.0
3400	COLSPRNG	-1275207.2	-4798029.3	3994208.3	9.1	5.1	5.7
3401	BDFRDMAS	1513136.1	-4463576.8	4283055.8	3.2	3.4	3.0
3402	SEMESALA	167259.7	-5481971.0	3245037.0	3.9	2.8	3.5
3404	SWANILND	642491.4	-6053940.3	1895688.6	4.7	3.7	4.9
3405	GRNDTURK	1919482.9	-5621088.1	2315775.3	3.3	3.5	4.0
3406	CRCADANT	2251800.2	-5816912.9	1327191.1	2.4	2.1	3.4
3407	TRINIDAD	2979891.1	-5513530.9	1181129.3	4.7	3.4	5.3
3413	NATALBZL	5186348.4	-3654222.4	-653018.9	2.1	2.2	2.7
3414	BRASILIA	4114977.8	-4554142.5	-1732154.0	7.7	6.1	7.2
3431	ASUNCION	3093045.4	-4870081.7	-2710823.0	7.6	6.5	10.8
3476	PARMARBO	3623277.3	-5214210.7	601515.3	2.2	2.0	3.0
3477	BOGOTACA	1744650.2	-6114286.7	532208.6	10.2	6.6	9.6
3478	MANUSAUS	3185777.0	-5514585.9	-347703.2	18.7	14.5	35.1
3499	QUITOECR	1280834.2	-6250955.9	-10800.6	3.6	3.4	4.1

Table 2.1-1 (cont)

NO.	NAME	U	V	W			
3648	HUNTERGA	832566.2	-5349540.7	3360585.3	3.6	2.5	3.6
3657	ABERDEEN	1186787.1	-4785193.1	4032882.3	3.1	3.0	3.0
3861	HMSTDFLA	961767.9	-5679156.6	2729883.5	3.0	2.3	2.6
3902	CHEYENNE	-1234700.7	-4651242.8	4174758.6	8.6	6.3	6.3
3903	HRNDONMD	1088989.7	-4843005.4	3991776.6	12.1	8.5	8.9
4050	PRETORIA	5051608.1	2726603.3	-2774166.8	3.2	3.2	4.4
4061	ATGUAIND	2881592.3	-5372523.9	1868024.4	3.3	3.5	4.3
4081	GRNDTURK	1920410.9	-5619417.8	2319128.5	3.3	3.6	4.0
4082	MRITILND	910567.2	-5539113.2	3017965.3	2.6	2.4	2.8
4280	VANDNBRG	-2671873.8	-4521210.5	3607490.4	3.8	3.3	3.6
4740	BRMDAIND	2308887.3	-4874298.2	3393082.1	3.3	3.1	3.8
4760 C	BRMDILND	2308896.6	-4874304.9	3393069.9	5.0	5.0	5.0
4840 C	WALOPIND	1263971.0	-4882273.1	3891536.3	5.0	4.0	5.0
4860 C	WALOPIND	1261586.3	-4881561.0	3893196.2	6.0	5.0	6.0
4946 C	WOMRAUST	-3999056.7	3750306.2	-3248686.4	9.0	9.0	10.0
5001	HRNDONMD	1088849.4	-4842948.7	3991840.2	3.6	3.0	3.7
5201	MOSESLKE	-2127802.2	-3785911.5	4656012.1	2.3	2.2	2.4
5410	SANDILND	-5618754.1	-258227.5	2997250.2	2.3	2.8	3.6
5648	STSTWART	794691.0	-5360051.1	3253082.4	3.6	2.5	3.6
5712	PARMARBO	3623289.8	-5214188.0	601673.2	2.1	2.0	2.9
5713	TERCEIRA	4433637.8	-2268153.2	3971656.8	2.0	2.2	2.5
5715	DAKARSNG	5884468.8	-1853580.1	1612760.1	1.6	2.0	2.3
5717	FORTLAMY	6023410.7	1617946.5	1331655.8	2.0	2.0	2.7
5720	ADSABABA	4900749.1	3968253.0	966354.7	2.0	2.1	2.9
5721	MSHDIRAN	2604404.8	4444122.3	3750344.3	2.1	2.1	2.7
5722	DGOGRCIA	1905127.0	6032287.5	-810716.2	3.5	4.1	4.3
5723	CHANGMAI	-941709.4	5967445.0	2039322.9	2.5	2.2	3.5
5726	ZAMBONGA	-3361946.8	5365837.0	763627.8	2.3	2.2	3.2
5730	WAKEILND	-5858574.6	1394467.2	2093847.4	2.1	2.5	3.1
5732	PAGOPAGO	-6099970.5	-997355.3	-1568570.9	3.6	3.5	4.1
5733	XMASILND	-5885333.9	-2448380.4	221670.7	2.7	2.9	3.9
5734	SHMYAIND	-3851799.0	396409.3	5051342.0	2.7	3.2	2.9
5735	NATALBZL	5186350.6	-3654223.7	-653018.9	2.0	2.1	2.5
5736	ASCONIND	6118340.3	-1571761.9	-878553.6	2.3	2.2	2.7
5739	TERCEIRA	4433629.3	-2268186.2	3971647.0	2.0	2.2	2.5
5744	CTNSICLY	4896437.7	1316125.0	3856626.2	1.8	2.2	2.3
5907	WRTINGTN	-449417.5	-4600905.5	4380288.1	4.2	3.2	4.5
5911	BRMDAIND	2307991.2	-4873773.2	3394463.4	2.6	2.3	3.0
5912	PANAMACA	1142644.5	-6196109.1	988336.6	3.1	3.4	4.1
5914	PURTRICO	2349456.9	-5576027.1	2010342.6	10.5	7.0	6.4
5915	AUSTINTX	-744091.1	-5465238.7	3192467.4	3.8	3.8	4.7
5923	CYPRSIND	4363332.2	2862254.9	3655380.7	1.9	2.1	2.4
5924	ROTASPAN	5093556.2	-565322.3	3784268.3	1.9	2.6	2.9
5925	RBRTFELD	6237366.3	-1140241.5	687740.2	2.3	2.6	2.0
5930	SNGAPORE	-1542549.4	6186956.7	151833.8	2.6	2.7	3.4
5931	HONGKONG	-2423914.9	5288250.3	2394869.2	2.5	2.5	3.6
5933	DRWNAUST	-4071568.4	4714253.3	-1366528.3	3.2	3.2	3.7
5934	MANUSAUS	-5367663.1	3437869.9	-225416.0	2.5	2.5	3.3

Table 2.1-1 (cont)

NO.	NAME	U	V	W			
5935	GUAMILND	-5059825.7	3591186.0	1472762.5	2.1	2.2	2.8
5937	PALUAIND	-4433463.6	4512930.3	809958.7	2.2	2.2	3.2
5938	GUDALCNL	-5915096.5	2146860.8	-1037909.5	3.0	3.0	3.5
5941	MAUIHWAI	-5467757.3	-2381246.7	2254033.8	2.5	2.8	3.8
6001	THULEGRD	546568.7	-1389993.7	6180236.7	2.6	2.4	3.4
6002	BLTVILMD	1130764.9	-4830831.9	3994704.0	2.0	1.7	1.9
6003	MOSESLKE	-2127832.1	-3785863.0	4656037.2	2.1	2.0	2.3
6004	SHMYAIND	-3851797.5	396409.4	5051340.5	2.7	3.3	3.9
6006	TRMSNRWY	2102927.4	721668.5	5958180.8	2.4	2.9	2.9
6007	TERCEIRA	4433637.3	-2268151.4	3971655.0	2.0	2.2	2.5
6008	PARMARBO	3623241.0	-5214233.7	601536.1	2.1	2.0	2.9
6009	QUITDECR	1280834.2	-6250955.9	-10800.6	3.6	3.4	4.1
6011	MAUIHWAI	-5466018.6	-2404431.5	2242224.4	3.0	2.9	3.3
6012	WAKEILND	-5858569.3	1394508.7	2093820.3	2.1	2.6	3.2
6013	KNYJAPAN	-3565892.8	4120713.6	3303428.3	3.3	4.4	4.9
6015	MSHDIRAN	2604353.3	4444166.0	3750220.5	2.1	2.2	2.6
6016	CTNSICLY	4896388.3	1316172.1	3856668.2	1.8	2.2	2.2
6019	VILDOLRS	2280627.1	-4914543.2	-3355402.8	2.4	2.7	3.7
6020	ESTRILND	-1888614.3	-5354894.4	-2895749.0	5.4	4.5	5.5
6022	TUTILAAS	-6099961.7	-997362.2	-1568585.5	3.4	3.6	4.7
6023	THRSILND	-4955386.8	3842247.8	-1163847.4	3.2	3.0	4.0
6031	INVRCRGL	-4313825.3	891333.9	-4597265.8	3.4	3.9	3.8
6032	CAVRSHAM	-2375420.6	4875546.7	-3345411.1	3.3	3.2	3.9
6038	SCROILND	-2160980.9	-5642710.5	2035367.8	2.5	2.8	3.8
6039	PTCRNIND	-3724765.9	-4421237.6	-2686084.7	6.2	5.4	5.5
6040	COCOSIND	-741981.7	6190792.9	-1338546.3	4.5	3.7	4.2
6042	ADSABABA	4900750.7	3968252.7	966325.3	2.0	2.1	2.9
6043	CERSMBRD	1371375.9	-3614750.3	-5055927.8	3.3	3.8	4.8
6044	HEARDIND	1098897.9	3684606.6	-5071873.1	6.8	6.2	7.8
6045	MAURTIUS	3223432.0	5045336.3	-2191805.7	3.2	3.1	3.9
6047	ZAMBONGA	-3361976.9	5365811.9	763624.7	2.4	2.3	3.2
6050	PAMERANT	1192678.8	-2451015.6	-5747034.2	4.9	6.1	6.1
6051	MAWSNANT	1111336.1	2169262.7	-5874334.1	4.9	3.7	4.4
6052	WLKESANT	-902608.8	2409522.1	-5816551.8	4.4	4.0	5.4
6053	MCMRDANT	-1310852.3	311257.5	-6213276.5	4.6	4.5	4.3
6055	ASCONIND	6118334.2	-1571748.3	-878596.5	2.3	2.3	2.8
6059	XMASILND	-5885333.5	-2448379.0	221671.1	2.7	2.9	3.8
6060	CULGOORA	-4751650.0	2792058.1	-3200164.0	3.3	3.3	3.7
6061	SGEORGIA	2999915.6	-2219369.3	-5155246.0	3.7	5.7	5.3
6063	DAKARSNG	5884467.4	-1853495.8	1612855.1	1.7	2.1	2.5
6064	FORTLAMY	6023386.7	1617931.9	1331733.2	2.7	2.6	3.2
6065	PISENBRG	4213564.6	820830.0	4702784.4	2.0	2.4	2.3
6066	WAKEILND	-5858571.2	1394466.4	2093846.0	2.1	2.6	3.2
6067	NATALBZL	5186397.1	-3653933.3	-654276.9	2.1	2.2	2.6
6068	JONSBURG	5084830.4	2670341.2	-2768095.2	3.0	2.9	4.2
6069	TNDACNHA	4978421.7	-1086874.0	-3823167.8	6.5	6.4	8.1
6072	CHANGMAI	-941702.1	5967455.1	2039311.6	5.7	4.0	4.3
6073	DGOGRCIA	1905134.1	6032282.4	-810732.7	3.4	3.7	4.2

Table 2.1-1 (cont.)

NO.		NAME	U	V	W			
6075		MAHEILND	3602820.6	5238240.7	-515948.3	3.9	3.6	4.0
6078		PORTVILA	-5952303.4	1231904.9	-1925972.5	9.7	8.0	12.4
6111		WRGTWOOD	-2448853.3	-4667985.8	3582754.9	2.6	2.1	2.4
6123		PTBARROW	-1881799.4	-812439.0	6019590.7	4.6	4.4	4.5
6134		WRGTWOOD	-2448907.0	-4668075.9	3582449.6	2.6	2.1	2.4
7034	C	GRNDFRKS	-521704.5	-4242064.3	4718716.8	5.0	5.0	4.0
7036		EDINBURG	-828487.0	-5657471.3	2816816.0	3.5	2.4	2.9
7037		COLUMBIA	-191291.0	-4967293.9	3983252.6	2.9	2.2	2.4
7039		BRMDAIND	2308213.4	-4873598.3	3394558.5	3.3	3.1	3.6
7040		SAN JUAN	2465049.5	-5534930.0	1985513.1	3.7	3.2	4.0
7043		GRENBELT	1130708.6	-4831331.3	3994135.5	2.0	1.7	1.9
7045		DNVERCOL	-1240470.2	-4760242.1	4048985.3	4.2	2.8	2.9
7050	C	GRENBELT	1130670.3	-4831367.2	3994104.0	4.0	3.0	4.0
7052	C	WALOPIND	1261545.1	-4881587.5	3892166.1	4.0	3.0	4.0
7053	T	GRENBELT	1130638.1	-4831360.6	3994149.6	6.0	6.0	6.0
7054	C	CAVNAUST	-2328216.4	5299636.8	-2669490.9	6.0	12.0	17.0
7071	C	JPTERFLA	976257.5	-5601406.0	2880230.9	4.0	4.0	4.0
7072		JPTERFLA	976251.3	-5601399.9	2880241.9	2.2	1.8	2.3
7073	C	JPTERFLA	976267.8	-5601399.1	2880240.0	5.0	5.0	5.0
7074	C	JPTERFLA	976268.4	-5601396.3	2880246.4	5.0	5.0	5.0
7075		SDBRYONT	692620.7	-4347076.5	4600475.4	3.7	3.8	3.4
7076		KINGSTON	1384158.7	-5905662.0	1966545.7	4.1	4.4	5.3
7077	C	GRENBELT	1130055.7	-4833042.4	3992258.0	4.0	3.0	4.0
7078	C	WALOPIND	1261576.5	-4881356.8	3893441.7	4.0	3.0	4.0
7079	C	CAVNAUST	-2328631.8	5299347.4	-2669682.9	7.0	13.0	18.0
7809	T	HAUTFNCE	4578327.5	457964.9	4403174.3	8.0	8.0	11.0
7816	T	STPHNION	4654320.2	1959163.4	3884368.0	13.0	13.0	13.0
7818	T	CLMDBHAR	5426310.7	-229340.2	3334616.4	13.0	13.0	13.0
7912	T	MAUIHWAI	-5466070.3	-2404290.3	2242183.7	10.0	10.0	10.0
8009		WIPOLDER	3923397.4	299869.4	5002975.5	8.5	10.1	6.9
8010		ZMERWALD	4331307.0	567490.8	4623108.2	5.7	8.3	5.4
8011		MLVRNENG	3920153.5	-134804.5	5012734.8	8.9	14.3	6.9
8015		HAUTFNCE	4578322.1	457936.5	4403195.3	4.2	8.0	4.4
8019		NICEFNCE	4579463.2	586573.5	4386419.2	4.1	7.9	4.3
8030		MUDDNENG	4205626.9	163683.4	4776540.6	6.5	9.7	5.8
8804	C	SANFRNDO	5105601.7	-555293.7	3769644.7	5.0	12.0	6.0
8815	C	HAUTFNCE	4578365.0	457920.7	4403150.9	6.0	10.0	6.0
8820	T	DAKARSNG	5886248.2	-1845660.0	1615260.7	12.0	14.0	16.0
9001		ORGNPASS	-1535750.7	-5167014.4	3401039.4	4.2	2.8	2.7
9002		OLFSFNTN	5056108.4	2716508.7	-2775768.8	3.0	3.0	4.2
9003	C	WOMRAUST	-3983807.5	3743068.5	-3275543.4	6.0	6.0	7.0
9004		SANFRNDO	5105581.5	-555271.5	3769676.0	3.4	10.0	4.0
9005		TKYJAPAN	-3946730.5	3366286.1	3698822.9	9.2	9.0	7.5
9006		NAINITAL	1018164.5	5471108.7	3109625.6	12.4	5.5	6.0
9007		AREQUIPA	1942760.9	-5804088.2	-1796900.9	2.5	2.9	4.4
9008		SHRZIRAN	3376875.2	4403976.2	3136257.3	6.8	6.1	6.1
9009		CRCADANT	2251810.7	-5816917.6	1327163.4	2.4	2.1	3.4
9010		JPTERFLA	976276.2	-5601402.2	2880234.5	2.1	1.8	2.3

Table 2.1-1 (cont)

NO.		NAME	U	V	W			
9011		VILDOLRS	2280575.3	-4914580.2	-3355383.7	2.4	2.7	3.7
9012		MAUIHWAI	-5466067.8	-2404312.7	2242188.4	3.0	2.9	3.3
9021		MTHPKINS	-1936789.3	-5077714.7	3331922.7	7.1	5.3	5.3
9022	T	OLFSFNTN	5056103.6	2716508.0	-2775771.3	7.0	7.0	7.0
9023	C	WOMRAUST	-3977795.7	3725081.8	-3303010.7	7.0	7.0	8.0
9025	C	DDRJAPAN	-3910474.4	3376348.0	3729210.1	11.0	11.0	9.0
9027	T	AREQUIPA	1942757.6	-5804104.5	-1796894.7	6.0	6.0	6.0
9028		ADSABABA	4903726.6	3965206.3	963859.6	2.1	2.1	2.9
9029		NATALBZL	5186441.4	-3653871.9	-654314.1	2.1	2.2	2.7
9031		CMDRRVDA	1693797.3	-4112353.1	-4556622.0	8.3	8.8	11.2
9039	T	NATALBZL	5186452.6	-3653855.6	-654320.7	9.0	9.0	9.0
9049	C	JPTERFLA	976266.3	-5601404.1	2880229.2	4.0	4.0	4.0
9050	T	HRVRDMAS	1489733.9	-4467483.4	4287304.9	12.0	11.0	15.0
9051		ATHNSGRC	4606861.5	2029692.2	3903562.2	4.2	10.3	4.4
9091		DIONYSOS	4595158.9	2039417.6	3912670.6	4.2	10.3	4.4
9424		COLDLAKE	-1264831.9	-3466915.4	5185450.9	4.7	5.5	4.3
9425		EWRDSAFB	-2450012.7	-4624431.6	3635036.6	2.6	2.2	2.4
9426		HARESTUA	3121261.3	592605.7	5512723.0	8.6	9.4	5.8
9427		JHSTNIND	-6007428.7	-1111852.5	1825733.9	8.9	19.8	8.6
9431		RIGALTVA	3183897.6	1421426.7	5322814.7	12.3	9.4	7.0
9432		UZHGOROD	3907419.2	1602378.6	4763922.1	7.9	10.4	5.9
9711	C	DSNCALIF	-2351452.4	-4645087.1	3673767.7	5.0	5.0	5.0
9712	C	DSNCALIF	-2350465.9	-4651987.1	3665632.7	5.0	5.0	5.0
9714	C	DSNCALIF	-2353644.5	-4641350.3	3677056.2	4.0	4.0	4.0
9741	C	JPL AUST	-3978731.3	3724832.0	-3302190.6	5.0	5.0	6.0
9742	C	JPL AUST	-4460996.9	2682397.8	-3674596.2	12.0	23.0	10.0
9751	C	JPLSAFRC	5085428.9	2668245.4	-2768706.6	5.0	5.0	6.0
9761	C	JPLSPAIN	4849230.8	-360340.2	4114880.5	8.0	12.0	6.0
9762	C	JPLSPAIN	4846688.5	-370258.6	4116903.7	9.0	13.0	7.0
9901	T	ORGNPASS	-1535779.5	-5166998.0	3401052.4	8.0	8.0	8.0
9902	C	OLFSFNTN	5056108.3	2716508.5	-2775768.7	5.0	5.0	6.0
9907	C	AREQUIPA	1942761.1	-5804088.7	-1796900.7	4.0	5.0	6.0
9921	C	MTHPKINS	-1936788.2	-5077711.7	3331927.9	9.0	7.0	7.0
9929	C	NATALBZL	5186441.7	-3653872.0	-654314.2	4.0	4.0	4.0
9930	C	DIONYSOS	4595215.1	2039399.9	3912624.2	6.0	12.0	6.0

Table 2.1-1 (cont.)

Table 2.4-2

RELATIONSHIPS BETWEEN VARIOUS GEODETIC SYSTEMS OR DATUMS

AND THE OSU 275 SYSTEM (DATUM-OSU275)

DATUM NAME	NO. OF STATIONS	DU(M)	DV(M)	DW(M)	OMEGA(")	PSI(")	EPSILON(")	DL($*10^6$)
AUSTRALIAN GEODETIC	16	156.2±3.8	58.8±3.8	−131.1±3.2				0.63±0.94
		155.0±0.8	59.9±0.8	−130.9±0.9	1.10±0.05	0.65±0.06	−0.43±0.06	−0.37±0.11
EUROPEAN DATUM 1950	31	125.5±7.4	139.0±4.0	151.2±8.0				−6.41±1.67
		101.5±3.0	130.1±3.2	117.1±3.0	−0.51±0.09	0.17±0.15	−0.95±0.10	−6.64±0.45
NORTH AMERICAN 1927	71	35.4±1.4	−164.0±3.1	−164.1±2.7				−2.86±0.61
		36.6±1.4	−150.2±1.3	−177.6±1.4	0.25±0.02	0.32±0.03	−0.78±0.04	−2.65±0.18
SOUTH AMERICAN 1969	28	71.3±2.6	31.0±3.7	40.1±1.5				5.44±0.67
		93.8±1.4	9.6±1.4	30.1±1.4	−0.39±0.05	0.24±0.04	−0.19±0.04	5.31±0.16

ω, ψ, ϵ when positive, represent counterclockwise rotations about the respective w, v, u axes, as viewed from the end of the positive axis.

IF (DATUM-GEOCENTER)IS SOUGHT ADD TO THE TABULATED VALUES OF DU, DV, DW, THE RESPECTIVE QUANTITIES -17m, -13m, AND +1m.

Table 2.1-2 (cont.)

DATUM NO.	DATUM NAME	NO. OF STATIONS	DU(M)	DV(M)	DW(M)
1	ADINDAN (ETHIOPIA)	11	167.1± 2.9	21.0± 2.9	-210.1± 3.1
2	AMERICAN SAMOA 1962	3	119.2± 0.0	-105.7± 0.0	-423.3± 0.0
3	ARC CAPE (SOUTH AFRICA)	8	151.7± 0.9	126.7± 0.9	298.1± 1.0
5	ASCENSION ISLAND	3	227.1± 0.4	-93.1± 0.4	-58.3± 0.5
10	CAMP AREA ASTRO 1961/62(USGS)	1	111.0±10.0	148.0± 9.0	-238.0±10.0
12	CHRISTMAS ISLAND ASTRO 1967	3	-115.8± 0.8	-221.8± 0.8	529.7± 0.8
15	EASTER ISLAND ASTRO 1967	1	-181.9± 0.0	-137.4± 0.0	-128.2± 0.0
17	GRACIOSA ISLAND (AZORES)	4	124.5± 0.4	-146.3± 0.4	37.3± 0.4
20	HEARD ASTRO 1969	1	181.5± 0.0	56.0± 0.0	-114.3± 0.0
22	INDIAN DATUM	1	-165.0±17.0	-711.0±10.0	-228.0±11.0
23	ISLA SOCORO ASTRO	2	-133.6± 0.1	-205.8± 0.1	-503.6± 0.1
24	JOHNSTON ISLAND 1961	1	-160.8± 0.0	50.7± 0.0	217.2± 0.0
26	LUZON 1911 (PHILIPPINES)	3	143.4± 5.9	50.5± 5.8	108.0± 6.2
27	MIDWAY ASTRO 1961	1	-377.4± 0.0	84.1± 0.0	-278.5± 0.0
28	NEW ZEALAND 1949	2	-61.8± 0.7	41.9± 0.8	-191.7± 0.8
33	OLD HAWAIIN	5	-50.4± 0.5	298.0± 0.6	185.2± 0.6
36	PITCAIRN ISLAND ASTRO	1	-167.1± 0.0	-168.6± 0.0	-59.9± 0.0
39	PROVISIONAL S. CHILE 1963	2	0.9± 0.6	-196.0± 0.6	-92.1± 0.7
42	SOUTHEAST ISLAND (MAHE)	3	50.0± 3.1	189.4± 2.9	270.9± 3.1
43	SOUTH GEORGIA ASTRO	1	820.3± 0.0	-101.0± 0.0	290.3± 0.0
45	TANANARIVE	2	191.9± 3.1	253.5± 3.1	122.2± 3.1
46	TOKYO DATUM	3	180.2± 3.4	-508.4± 3.7	-679.0± 3.6
47	TRISTAN ASTRO 1968	1	653.7± 0.0	-420.3± 0.0	622.3± 0.0
49	WAKE ISLAND ASTRO 1952	5	-259.7± 0.6	66.5± 0.7	-140.6± 0.7
51	PALMER ASTRO 1969	2	-208.0± 8.3	-16.5± 8.4	-220.3± 8.4
52	EFATE (NEW HEBRIDES)	1	139.5± 0.0	791.5± 0.0	-452.8± 0.0
53	LE POUCI ASTRO	1	755.1± 0.0	-155.8± 0.0	506.6± 0.0
54	DIEGO GARCIA ASTRO 1969	2	-185.8± 8.8	438.5± 9.2	238.0± 9.5

Table 2.I-3

TRANSFORMATION PARAMETERS

(SATELLITE GEODETIC SYSTEM - OSU 275 SYSTEM)

	NO. OF STATIONS	DU(M)	DV(M)	DW(M)	OMEGA(")	PSI(")	EPSILON(")	DL($*10^6$)
NGS (DYNAMIC)	45	18.8±0.9	9.3±0.9	-3.2±1.0	0.08±0.01	-0.06±0.01	-0.08±0.01	-2.28±0.03
NWL - 9D	50	19.8±1.0	9.1±0.9	-2.6±1.1	0.43±0.01	-0.12±0.01	-0.13±0.01	0.09±0.03
GSFC 1973	67	13.2±1.2	16.8±1.2	-2.2±1.6	-0.42±0.01	0.17±0.01	0.17±0.01	1.16±0.05
STD. EARTH III	101	15.0±1.0	14.6±1.0	-13.3±1.0	0.27±0.01	0.06±0.01	0.01±0.01	0.73±0.03
WGS - 1972	124	18.3±0.6	9.6±0.6	-13.6±0.6	0.02±0.00	-0.12±0.00	-0.13±0.00	-0.95±0.01
GEM 6	134	17.8±0.7	12.0±0.7	5.2±0.7	0.13±0.00	0.07±0.00	0.02±0.00	0.84±0.02

ω, ϕ, ϵ when positive, represent counterclockwise rotations about the respective w, v, u axes, as viewed from the end of the positive axis.

2.2 Determination of Transformation Parameters in case of Limited Area Coverage

2.21 Devloping Moledensky's and Veis' Models:

The general transformation model (equation 1, section 2.5 of the Tenth Semi-annual Status Report of OSURF Project No. 2514 covering the period January-June 1972) is known after Bursa. Thus, to expand the scope of transformation program, Molodensky's and Veis' models, especially suitable for limited area coverage, were also programmed and incorporated. If the rectangular and spherical coordinates of the origin of the geodetic system to be transformed are U_0, V_0, W_0 and φ_0, λ_0, h_0, then the two models are given below:

Molodensky's Model

$$\begin{bmatrix}\varphi_1\\ \varphi_2\\ \varphi_3\end{bmatrix} \equiv \begin{bmatrix}X\\ Y\\ Z\end{bmatrix}_1 - \begin{bmatrix}U\\ V\\ W\end{bmatrix}_1 - \begin{bmatrix}\Delta x\\ \Delta y\\ \Delta z\end{bmatrix} - \begin{bmatrix}0 & \omega & -\psi\\ -\omega & 0 & \epsilon\\ \psi & -\epsilon & 0\end{bmatrix} \begin{bmatrix}U-U_0\\ V-V_0\\ W-W_0\end{bmatrix}_1 - \Delta \begin{bmatrix}U-U_0\\ V-V_0\\ W-W_0\end{bmatrix}_1 = 0 \qquad (1)$$

Veis' Model

$$\begin{bmatrix}\varphi_1\\ \varphi_2\\ \varphi_3\end{bmatrix} \equiv \begin{bmatrix}X\\ Y\\ Z\end{bmatrix}_1 - \begin{bmatrix}U\\ V\\ W\end{bmatrix}_1 - \begin{bmatrix}\Delta x\\ \Delta y\\ \Delta z\end{bmatrix} - M \begin{bmatrix}U-U_0\\ V-V_0\\ W-W_0\end{bmatrix}_1 - \Delta \begin{bmatrix}U-U_0\\ V-V_0\\ W-W_0\end{bmatrix}_1 \qquad (2)$$

Where matrix M is given as

$$M = \begin{bmatrix} 0 & \sin\varphi_0 \, dA - \cos\varphi_0 \, d\eta & -\cos\varphi_0 \sin\lambda_0 \, dA - \cos\lambda_0 \, d\xi - \sin\varphi_0 \sin\lambda_0 \, d\eta \\ -\sin\varphi_0 \, dA + \cos\varphi_0 \, d\eta & 0 & \cos\varphi_0 \cos\lambda_0 \, dA - \sin\lambda_0 \, d\xi + \sin\varphi_0 \cos\lambda_0 \, d\eta \\ \cos\varphi_0 \sin\lambda_0 \, dA + \cos\lambda_0 \, d\xi + \sin\varphi_0 \sin\lambda_0 \, d\eta & -\cos\varphi_0 \cos\lambda_0 \, dA + \sin\lambda_0 \, d\xi - \sin\varphi_0 \cos\lambda_0 \, d\eta & 0 \end{bmatrix}$$

The positive directions of the axes considered at the geodetic initial point (U_0, V_0, W_0) are south, east and along the ellipsoidal normal outwards with the respective rotations about these axes as $d\eta$, $d\xi$, dA.

The rotations in the above two models are related as under:

$$
\begin{aligned}
\omega &= \sin\varphi_0 \, dA - \cos\varphi_0 \, d\eta \\
\psi &= \cos\varphi_0 \sin\lambda_0 \, dA + \cos\lambda_0 \, d\xi + \sin\varphi_0 \sin\lambda_0 \, d\eta \\
\epsilon &= \cos\varphi_0 \cos\lambda_0 \, dA - \sin\lambda_0 \, d\xi + \sin\varphi_0 \cos\lambda_0 \, d\eta
\end{aligned} \qquad (3)
$$

However, it may be clarified that Molodensky's model for a global system would be identical to that of Bursa's (i.e., when $U_0 = V_0 = W_0 = 0$).

2.22 Applying Above Models to Various Datums:

The above models were then used to obtain the transformation parameters in respect of 4 major datum viz North American, European, South American and Australian datums [Table 13 of Attachment 2.2 of Thirteenth Semi-Annual Status Report covering period July-December 73].

The results are given below:

A. <u>Australian → WN14</u>

(i) Molodensky's Model (Table 2.2-1a & b)
(ii) Veis' Model (Table 2.2-2)

B. <u>European-50 → WN14</u>

(a) European-50 (W)
(i) Molodensky's Model (Table 2.2-3a & b)

(b) European-50 (All Stations)
(i) Molodensky's Model (Table 2.2-4a & b)
(ii) Veis' Model (Table 2.2-5)

C. <u>North American 1927</u>

(a) NAD-27 (W)
(i) Molodensky's Model (Table 2.2-6a & b)

(b) NAD-27 (E)
(i) Molodensky's Model (Table 2.2-7a & b)

(c) NAD-27 (All Stations)

(i) Molodensky's Model (Table 2.2-8a & b)
(ii) Veis' Model (Table 2.2-9)

D. <u>South American 1969</u>

(i) Molodensky's Model (Table 2.2 10a & b)
(ii) Veis' Model (Table 2.2-11)

A summary of the results is presented in Table 2.2-12.

AUS.NAT. -TO- WN- 14 (MO'SKY MODEL)
****

SOLUTION FOR 3 TRANSLATION AND 1 SCALE PARAMETERS
(UNITS - METERS)

(USING VARIANCES ONLY)

DX METERS	DY METERS	DZ METERS	DL (X1.D+6)
-0.15425371D+03	-0.59494780D+02	0.13226663D+03	0.92134200D+00

VARIANCE - COVARIANCE MATRIX

MO2= 3.58

0.24778961D+02	0.30233724D+00	-0.15903610D+00	0.89258015D-06
0.30233724D+00	0.24936962D+02	-0.51277044D+00	0.28778919D-05
-0.15903610D+00	-0.51277044D+00	0.29829711D+02	-0.15138351D-05
0.89258015D-06	0.28778919D-05	-0.15138351D-05	0.84963043D-11

COEFFICIENTS OF CORRELATION

0.10000000D+01	0.12162653D-01	-0.58496470D-02	0.61516362D-01
0.12162653D-01	0.10000000D+01	-0.18800816D-01	0.19771412D+00
-0.58496470D-02	-0.18800816D-01	0.10000000D+01	-0.95090912D-01
0.61516362D-01	0.19771412D+00	-0.95090912D-01	0.10000000D+01

Table 2.2-1a

Table 2.2-1a (cont.)

RESIDUALS V

V1(AUS.NAT.)				V2(WN- 14)				V1 - V2		
6023	-2.4	1.0	-5.8	6023	2.3	-1.1	3.7	-4.7	2.0	-9.5
6032	5.4	-2.6	6.4	6032	-5.0	2.6	-4.2	10.4	-5.2	10.6
6060	-2.9	1.6	-0.7	6060	2.7	-1.5	0.5	-5.7	3.1	-1.3

UNIT OF RESIDUALS (METERS)

Table 2.2-1b

AUS.NAT. -TO- WN- 14 (MO'SKY MODEL)
****

SCALE FACTOR AND ROTATION PARAMETERS CONSTRAINED

SOLUTION FOR 3 TRANSLATION, 1 SCALE AND 3 ROTATION PARAMETERS

(USING VARIANCES ONLY)

DU METERS	DV METERS	DW METERS	DELTA (X1.D+6)	OMEGA SECONDS	PSI SECONDS	EPSILON SECONDS
-156.97	-59.14	131.23	1.20	-1.03	-0.99	0.25

VARIANCE - COVARIANCE MATRIX

SO2= 0.48

0.341D+01	0.615D-02	0.258D-01	0.511D-07	0.236D-06	0.104D-06	-0.628D-07
0.615D-02	0.331D+01	0.444D-01	0.172D-06	0.125D-07	-0.775D-07	-0.224D-06
0.258D-01	0.444D-01	0.410D+01	-0.903D-07	0.135D-06	-0.560D-07	-0.384D-06
0.511D-07	0.172D-06	-0.903D-07	0.507D-12	0.335D-14	-0.155D-13	-0.457D-14
0.236D-06	0.125D-07	0.135D-06	0.335D-14	0.765D-12	-0.148D-12	-0.408D-12
0.104D-06	-0.775D-07	-0.560D-07	-0.155D-13	-0.148D-12	0.748D-12	0.379D-12
-0.628D-07	-0.224D-06	-0.384D-06	-0.457D-14	-0.408D-12	0.379D-12	0.114D-11

COEFFICIENTS OF CORRELATION

0.100D+01	0.183D-02	0.690D-02	0.389D-01	0.146D+00	0.652D-01	-0.318D-01
0.183D-02	0.100D+01	0.120D-01	0.133D+00	0.787D-02	-0.492D-01	-0.115D+00
0.690D-02	0.120D-01	0.100D+01	-0.626D-01	0.763D-01	-0.320D-01	-0.177D+00
0.389D-01	0.133D+00	-0.626D-01	0.100D+01	0.539D-02	-0.252D-01	-0.600D-02
0.146D+00	0.787D-02	0.763D-01	0.539D-02	0.100D+01	-0.196D+00	-0.436D+00
0.652D-01	-0.492D-01	-0.320D-01	-0.252D-01	-0.196D+00	0.100D+01	0.410D+00
-0.318D-01	-0.115D+00	-0.177D+00	-0.600D-02	-0.436D+00	0.410D+00	0.100D+01

Table 2.2-1b (cont.)

RESIDUALS V

V1(AUS.NAT.)				V2(WN- 14)				V1 - V2		
6023	0.9	-0.4	-2.9	6023	-0.8	0.4	1.8	1.7	-0.8	-4.8
6032	1.0	1.2	0.7	6032	-0.9	-1.2	-0.5	2.0	2.4	1.2
6060	-1.9	-0.8	1.9	6060	1.8	0.7	-1.4	-3.7	-1.5	3.2

UNIT OF RESIDUALS (METERS)

Table 2.2-2

AUS.NAT. -TO- WN- 14 (VEIS MODEL)
****

SOLUTION FOR 3 TRANSLATION, 1 SCALE AND 3 ROTATION PARAMETERS

(USING VARIANCES ONLY)

DU METERS	DV METERS	DW METERS	DELTA (X1.D+6)	ALPHA SECONDS	KSI SECONDS	ETA SECONDS
-156.97	-59.17	131.22	1.14	-0.35	0.47	1.32

VARIANCE - COVARIANCE MATRIX

SO2= 1.40

0.104D+02	0.262D-01	0.200D+00	0.316D-06	0.195D-07	-0.171D-06	-0.193D-05
0.262D-01	0.101D+02	0.341D+00	0.114D-05	0.563D-06	0.161D-05	-0.387D-06
0.200D+00	0.341D+00	0.126D+02	-0.594D-06	0.103D-05	0.229D-05	-0.160D-05
0.316D-06	0.114D-05	-0.594D-06	0.333D-11	-0.144D-12	0.229D-12	0.888D-14
0.195D-07	0.563D-06	0.103D-05	-0.144D-12	0.336D-11	-0.161D-12	-0.158D-12
-0.171D-06	0.161D-05	0.229D-05	0.229D-12	-0.161D-12	0.974D-11	-0.317D-11
-0.193D-05	-0.387D-06	-0.160D-05	0.888D-14	-0.158D-12	-0.317D-11	0.629D-11

COEFFICIENTS OF CORRELATION

0.100D+01	0.255D-02	0.174D-01	0.535D-01	0.329D-02	-0.169D-01	-0.238D+00
0.255D-02	0.100D+01	0.301D-01	0.196D+00	0.967D-01	0.163D+00	-0.486D-01
0.174D-01	0.301D-01	0.100D+01	-0.914D-01	0.158D+00	0.206D+00	-0.179D+00
0.535D-01	0.196D+00	-0.914D-01	0.100D+01	-0.432D-01	0.402D-01	0.194D-02
0.329D-02	0.967D-01	0.158D+00	-0.432D-01	0.100D+01	-0.281D-01	-0.344D-01
-0.169D-01	0.163D+00	0.206D+00	0.402D-01	-0.281D-01	0.100D+01	-0.405D+00
-0.238D+00	-0.486D-01	-0.179D+00	0.194D-02	-0.344D-01	-0.405D+00	0.100D+01

NOTE : THE POSITIVE ROTATIONS ARE TOWARDS SOUTH, EAST, AND ALONG ELLIPSOIDAL NORMAL UPWARDS.

Table 2.2-2 (cont.)

RESIDUALS V

V1(AUS.NAT.)				V2(WN- 14)				V1 - V2		
6023	0.9	-0.4	-3.0	6023	-0.8	0.4	1.9	1.7	-0.8	-4.9
6032	1.0	1.2	0.7	6032	-0.9	-1.1	-0.5	1.9	2.3	1.2
6060	-1.9	-0.8	1.9	6060	1.7	0.7	-1.4	-3.6	-1.5	3.3

UNIT OF RESIDUALS (METERS)

ED-50(W) -TO- WN-14 (MO'SKY MODEL)
****

SOLUTION FOR 3 TRANSLATION AND 1 SCALE PARAMETERS
(UNITS - METERS)

(USING VARIANCES ONLY)

DX METERS	DY METERS	DZ METERS	DL (X1.D+6)
-0.10097402D+03	-0.12745500D+03	-0.11607371D+03	0.84220527D+01

VARIANCE - COVARIANCE MATRIX

MO2= 0.86

0.20539159D+02	-0.94768524D+00	-0.25813405D+01	-0.66502801D-05
-0.94768524D+00	0.20076482D+02	0.96613360D+00	0.24890397D-05
-0.25813405D+01	0.96613360D+00	0.20535452D+02	0.67797395D-05
-0.66502801D-05	0.24890397D-05	0.67797395D-05	0.17466571D-10

COEFFICIENTS OF CORRELATION

0.10000000D+01	-0.46669052D-01	-0.12569032D+00	-0.35111129D+00
-0.46669052D-01	0.10000000D+01	0.47581841D-01	0.13291812D+00
-0.12569032D+00	0.47581841D-01	0.10000000D+01	0.35797858D+00
-0.35111129D+00	0.13291812D+00	0.35797858D+00	0.10000000D+01

Table 2.2-3a

Table 2.2-3a (cont.)

RESIDUALS V

	V1(ED-50(W))				V2(WN- 14)			V1 - V2		
6006	0.0	1.1	-0.4	6006	-1.8	-33.6	11.9	1.9	34.7	-12.3
6016	-0.3	0.9	0.0	6016	13.6	-25.7	-1.4	-13.9	26.5	1.4
6065	-0.2	0.7	0.3	6065	2.8	-8.7	-3.5	-3.0	9.4	3.8
8009	2.8	-1.2	-0.4	8009	-9.8	3.0	2.1	12.6	-4.1	-2.5
8010	1.3	-2.8	-0.9	8010	-10.0	10.3	7.7	11.3	-13.1	-8.5
8015	0.1	-7.3	0.2	8015	-0.7	16.5	-1.3	0.8	-23.9	1.5
8019	0.0	-2.4	0.1	8019	-0.3	23.7	-2.0	0.3	-26.0	2.0
8030	1.6	-9.5	-0.3	8030	-5.5	14.6	1.4	7.1	-24.1	-1.7
9004	-0.1	-2.5	0.0	9004	10.9	26.2	-1.6	-11.0	-28.7	1.6
9091	0.3	-7.6	0.3	9091	-7.0	31.9	-5.7	7.3	-39.5	6.0
9426	-0.1	-2.0	0.4	9426	0.4	9.9	-4.7	-0.5	-11.8	5.1

UNIT OF RESIDUALS (METERS)

Table 2.2-3b

ED-50(W) -TO- WN- 14 (MO'SKY MODEL)
****

SCALE FACTOR AND ROTATION PARAMETERS CONSTRAINED

SOLUTION FOR 3 TRANSLATION, 1 SCALE AND 3 ROTATION PARAMETERS

(USING VARIANCES ONLY)

DU METERS	DV METERS	DW METERS	DELTA (X1.D+6)	OMEGA SECONDS	PSI SECONDS	EPSILON SECONDS
-99.58	-124.88	-116.37	7.75	1.37	-0.04	0.13

VARIANCE - COVARIANCE MATRIX

SD2= 0.82

0.181D+02	-0.196D-01	0.421D+00	-0.736D-06	0.125D-05	-0.146D-05	-0.956D-06
-0.196D-01	0.195D+02	-0.165D+00	0.275D-06	0.572D-06	0.168D-07	0.159D-05
0.421D+00	-0.165D+00	0.181D+02	0.753D-06	0.974D-06	-0.140D-05	-0.162D-05
-0.736D-06	0.275D-06	0.753D-06	0.194D-11	0.377D-14	-0.622D-15	-0.703D-14
0.125D-05	0.572D-06	0.974D-06	0.377D-14	0.588D-11	-0.788D-12	-0.406D-11
-0.146D-05	0.168D-07	-0.140D-05	-0.622D-15	-0.788D-12	0.338D-11	0.785D-12
-0.956D-06	0.159D-05	-0.162D-05	-0.703D-14	-0.406D-11	0.785D-12	0.793D-11

COEFFICIENTS OF CORRELATION

0.100D+01	-0.104D-02	0.233D-01	-0.124D+00	0.121D+00	-0.186D+00	-0.797D-01
-0.104D-02	0.100D+01	-0.878D-02	0.446D-01	0.534D-01	0.207D-02	0.128D+00
0.233D-01	-0.878D-02	0.100D+01	0.127D+00	0.945D-01	-0.179D+00	-0.135D+00
-0.124D+00	0.446D-01	0.127D+00	0.100D+01	0.112D-02	-0.243D-03	-0.179D-02
0.121D+00	0.534D-01	0.945D-01	0.112D-02	0.100D+01	-0.177D+00	-0.594D+00
-0.186D+00	0.207D-02	-0.179D+00	-0.243D-03	-0.177D+00	0.100D+01	0.152D+00
-0.797D-01	0.128D+00	-0.135D+00	-0.179D-02	-0.594D+00	0.152D+00	0.100D+01

Table 2.2-3b (cont.)

RESIDUALS V

V1(ED-50(W))				V2(WN- 14)				V1 - V2		
6006	-0.0	-0.7	0.4	6006	0.2	19.5	-11.4	-0.2	-20.1	11.8
6016	0.4	-1.0	-0.0	6016	-16.8	31.3	1.4	17.2	-32.3	-1.4
6065	0.2	-0.7	-0.3	6065	-3.5	9.1	3.6	3.6	-9.8	-3.9
8009	-3.3	1.8	0.4	8009	11.8	-4.5	-2.1	-15.2	6.3	2.5
8010	-1.4	2.5	0.9	8010	11.0	-9.5	-7.7	-12.5	12.1	8.6
8015	-0.3	6.5	-0.1	8015	2.5	-14.6	1.1	-2.8	21.1	-1.3
8019	-0.0	2.1	-0.1	8019	1.5	-21.1	1.8	-1.5	23.2	-1.9
8030	-2.4	9.5	0.4	8030	8.3	-14.7	-1.6	-10.8	24.3	2.0
9004	0.0	2.0	-0.0	9004	-1.7	-20.8	0.3	1.8	22.8	-0.4
9091	0.0	6.8	-0.3	9091	-1.0	-28.5	6.1	1.1	35.3	-6.4
9426	0.1	3.2	-0.4	9426	-0.5	-16.2	5.0	0.5	19.4	-5.4

UNIT OF RESIDUALS (METERS)

ED- 50 -TO- WN- 14 (MO'SKY MODEL)
****

SOLUTION FOR 3 TRANSLATION AND 1 SCALE PARAMETERS
(UNITS - METERS)

(USING VARIANCES ONLY)

DX METERS	DY METERS	DZ METERS	DL (X1.D+6)
-0.99423365D+02	-0.13319840D+03	-0.11672295D+03	0.60713702D+01

VARIANCE - COVARIANCE MATRIX

MO2= 1.04

0.19396462D+02	0.30218359D+00	-0.74350241D+00	-0.16483633D-05
0.30218359D+00	0.20753629D+02	-0.62140004D+00	-0.13776593D-05
-0.74350241D+00	-0.62140004D+00	0.20243359D+02	0.33896381D-05
-0.16483633D-05	-0.13776593D-05	0.33896381D-05	0.75149119D-11

COEFFICIENTS OF CORRELATION

0.10000000D+01	0.15061305D-01	-0.37521469D-01	-0.13653052D+00
0.15061305D-01	0.10000000D+01	-0.30216772D-01	-0.11031457D+00
-0.37521469D-01	-0.30216772D-01	0.10000000D+01	0.27482112D+00
-0.13653052D+00	-0.11031457D+00	0.27482112D+00	0.10000000D+01

Table 2.2-4a

Table 2.2-4a (cont.)

RESIDUALS V

	V1(ED- 50)				V2(WN- 14)			V1 - V2		
6006	0.1	-1.3	0.3	6006	-3.6	38.8	-9.2	3.7	-40.1	9.5
6015	0.0	0.0	0.2	6015	-8.8	-1.8	-22.1	8.8	1.8	22.2
6016	0.3	-1.1	0.0	6016	-12.6	32.2	-0.7	12.9	-33.3	0.7
6065	0.2	-1.1	-0.3	6065	-3.4	13.9	3.4	3.6	-15.0	-3.7
8009	-2.5	-0.1	0.3	8009	8.9	0.2	-1.6	-11.3	-0.2	1.9
8010	-1.2	1.7	0.9	8010	9.8	-6.4	-7.9	-11.0	8.1	8.8
8011	-0.3	9.9	-0.1	8011	2.6	-30.4	0.7	-2.9	40.3	-0.8
8015	-0.1	5.9	-0.1	8015	0.9	-13.2	0.6	-1.0	19.1	-0.7
8019	-0.0	1.9	-0.0	8019	0.6	-19.1	1.2	-0.6	21.0	-1.2
8030	-1.4	7.9	0.3	8030	5.0	-12.1	-1.4	-6.5	20.0	1.7
9004	0.1	2.3	0.0	9004	-9.4	-24.0	-0.7	9.5	26.4	0.7
9006	-2.2	0.2	0.3	9006	8.9	-4.5	-4.9	-11.1	4.8	5.1
9008	-0.8	0.9	1.2	9008	10.9	-15.8	-20.5	-11.7	16.8	21.7
9091	-0.3	6.0	-0.2	9091	7.3	-25.1	3.8	-7.6	31.1	-4.0
9426	0.5	1.1	-0.5	9426	-3.1	-5.6	6.4	3.7	6.7	-6.9
9431	-0.6	13.5	-3.6	9431	1.8	-67.9	32.5	-2.4	81.3	-36.1

UNIT OF RESIDUALS (METERS)

Table 2.2-4b

ED- 50 -TO- WN- 14 (MO'SKY MODEL)

****

SCALE FACTOR AND ROTATION PARAMETERS CONSTRAINED

SOLUTION FOR 3 TRANSLATION, 1 SCALE AND 3 ROTATION PARAMETERS

(USING VARIANCES ONLY)

DU METERS	DV METERS	DW METERS	DELTA (X1.D+6)	OMEGA SECONDS	PSI SECONDS	EPSILON SECONDS
-99.43	-132.00	-115.98	6.75	0.31	-0.14	0.48

VARIANCE - COVARIANCE MATRIX

SO2= 1.03

0.193D+02	0.187D+00	0.172D+00	-0.153D-06	0.101D-06	-0.102D-05	0.306D-06
0.187D+00	0.206D+02	0.100D+00	-0.129D-06	0.228D-06	-0.406D-06	0.597D-06
0.172D+00	0.100D+00	0.188D+02	0.316D-06	0.109D-06	-0.557D-06	0.302D-06
-0.153D-06	-0.129D-06	0.316D-06	0.700D-12	-0.168D-14	-0.167D-15	-0.241D-15
0.101D-06	0.228D-06	0.109D-06	-0.165D-14	0.105D-11	-0.490D-12	0.986D-13
-0.102D-05	-0.406D-06	-0.557D-06	-0.167D-15	-0.490D-12	0.236D-11	-0.698D-12
0.306D-06	0.597D-06	0.302D-06	-0.241D-15	0.986D-13	-0.698D-12	0.126D-11

COEFFICIENTS OF CORRELATION

0.100D+01	0.936D-02	0.901D-02	-0.417D-01	0.225D-01	-0.151D+00	0.621D-01
0.936D-02	0.100D+01	0.508D-02	-0.339D-01	0.491D-01	-0.583D-01	0.117D+00
0.901D-02	0.508D-02	0.100D+01	0.870D-01	0.246D-01	-0.837D-01	0.621D-01
-0.417D-01	-0.339D-01	0.870D-01	0.100D+01	-0.196D-02	-0.130D-03	-0.256D-03
0.225D-01	0.491D-01	0.246D-01	-0.196D-02	0.100D+01	-0.312D+00	0.858D-01
-0.151D+00	-0.583D-01	-0.837D-01	-0.130D-03	-0.312D+00	0.100D+01	-0.405D+00
0.621D-01	0.117D+00	0.621D-01	-0.256D-03	0.858D-01	-0.405D+00	0.100D+01

Table 2.2-4b (cont.)

RESIDUALS V

	V1(ED- 50)				V2(WN- 14)			V1 - V2		
6006	0.1	-1.1	0.4	6006	-2.9	33.2	-12.0	2.9	-34.3	12.4
6015	0.1	0.0	0.1	6015	-12.4	-4.3	-14.6	12.4	4.3	14.7
6016	0.3	-1.2	-0.0	6016	-13.1	35.0	1.1	13.4	-36.2	-1.1
6065	0.2	-1.1	-0.2	6065	-3.3	14.1	3.1	3.5	-15.3	-3.3
8009	-2.7	0.1	0.6	8009	9.5	-0.2	-3.3	-12.2	0.3	3.9
8010	-1.3	1.6	1.0	8010	10.1	-5.8	-8.7	-11.4	7.3	9.7
8011	-0.5	10.0	0.2	8011	3.9	-30.7	-2.1	-4.3	40.6	2.2
8015	-0.2	5.4	0.0	8015	1.4	-12.1	-0.1	-1.6	17.4	0.1
8019	-0.0	1.8	-0.0	8019	0.9	-17.6	0.7	-1.0	19.3	-0.7
8030	-1.7	7.7	0.7	8030	5.8	-11.9	-2.9	-7.4	19.5	3.6
9004	0.1	1.9	0.0	9004	-7.3	-19.8	-3.0	7.4	21.7	3.1
9006	-1.5	0.4	-0.2	9006	6.0	-8.4	3.9	-7.5	8.8	-4.1
9008	-0.5	0.9	0.7	9008	7.5	-15.7	-12.5	-8.1	16.6	13.3
9091	-0.2	5.7	-0.3	9091	5.9	-23.6	6.9	-6.1	29.3	-7.2
9426	0.4	1.6	-0.3	9426	-2.6	-8.2	4.4	3.1	9.9	-4.7
9431	-0.5	14.0	-3.6	9431	1.4	-70.5	32.4	-1.9	84.5	-36.0

UNIT OF RESIDUALS (METERS)

Table 2.2-5

ED- 50 -TO- WN- 14 (VEIS MODEL)
****

SOLUTION FOR 3 TRANSLATION, 1 SCALE AND 3 ROTATION PARAMETERS

(USING VARIANCES ONLY)

DU METERS	DV METERS	DW METERS	DELTA (X1.D+6)	ALPHA SECONDS	KSI SECONDS	ETA SECONDS
-99.39	-132.21	-116.44	6.06	0.30	-0.13	0.26

VARIANCE - COVARIANCE MATRIX

SO2= 1.11

0.246D+02	0.155D+01	0.129D+01	-0.172D-05	0.702D-06	-0.914D-05	-0.229D-07
0.155D+01	0.251D+02	0.711D+00	-0.151D-05	0.457D-05	-0.441D-05	0.279D-05
0.129D+01	0.711D+00	0.228D+02	0.361D-05	0.151D-05	-0.524D-05	0.825D-06
-0.172D-05	-0.151D-05	0.361D-05	0.800D-11	-0.159D-12	-0.199D-13	0.936D-13
0.702D-06	0.457D-05	0.151D-05	-0.159D-12	0.987D-11	-0.496D-11	-0.141D-12
-0.914D-05	-0.441D-05	-0.524D-05	-0.199D-13	-0.496D-11	0.224D-10	-0.211D-12
-0.229D-07	0.279D-05	0.825D-06	0.936D-13	-0.141D-12	-0.211D-12	0.114D-10

COEFFICIENTS OF CORRELATION

0.100D+01	0.624D-01	0.544D-01	-0.123D+00	0.451D-01	-0.390D+00	-0.136D-02
0.624D-01	0.100D+01	0.297D-01	-0.106D+00	0.290D+00	-0.186D+00	0.165D+00
0.544D-01	0.297D-01	0.100D+01	0.267D+00	0.101D+00	-0.232D+00	0.511D-01
-0.123D+00	-0.106D+00	0.267D+00	0.100D+01	-0.179D-01	-0.149D-02	0.979D-02
0.451D-01	0.290D+00	0.101D+00	-0.179D-01	0.100D+01	-0.334D+00	-0.133D-01
-0.390D+00	-0.186D+00	-0.232D+00	-0.149D-02	-0.334D+00	0.100D+01	-0.132D-01
-0.136D-02	0.165D+00	0.511D-01	0.979D-02	-0.133D-01	-0.132D-01	0.100D+01

NOTE : THE POSITIVE ROTATIONS ARE TOWARDS SOUTH, EAST, AND ALONG ELLIPSOIDAL NORMAL UPWARDS.

Table 2.2-5 (cont.)

RESIDUALS V

V1(ED- 50)				V2(WN- 14)				V1 - V2		
6006	0.1	-1.2	0.3	6006	-3.8	35.4	-10.0	3.8	-36.6	10.3
6015	0.0	0.0	0.1	6015	-10.0	-0.7	-15.5	10.0	0.7	15.6
6016	0.3	-1.1	-0.0	6016	-12.6	33.9	0.0	12.9	-35.1	-0.0
6065	0.2	-1.1	-0.2	6065	-3.3	13.8	3.1	3.5	-14.9	-3.3
8009	-2.5	0.2	0.5	8009	9.0	-0.5	-2.8	-11.5	0.7	3.3
8010	-1.3	1.7	1.0	8010	9.9	-6.4	-8.7	-11.2	8.1	9.7
8011	-0.4	10.1	0.1	8011	2.9	-31.1	-1.4	-3.2	41.3	1.5
8015	-0.1	5.7	0.0	8015	1.1	-12.9	-0.3	-1.3	18.6	0.3
8019	-0.0	1.9	-0.0	8019	0.8	-18.5	0.4	-0.8	20.4	-0.4
8030	-1.5	8.0	0.6	8030	5.2	-12.3	-2.7	-6.7	20.4	3.3
9004	0.1	2.2	0.1	9004	-8.7	-22.2	-3.6	8.8	24.4	3.7
9006	-1.9	0.1	-0.2	9006	7.7	-2.8	3.0	-9.6	2.9	-3.2
9008	-0.7	0.8	0.8	9008	9.9	-13.3	-14.2	-10.6	14.1	15.1
9091	-0.3	5.7	-0.3	9091	7.0	-23.8	5.9	-7.3	29.5	-6.1
9426	0.5	1.5	-0.4	9426	-3.1	-7.5	5.5	3.7	9.0	-5.9
9431	-0.6	13.8	-3.7	9431	1.6	-69.4	33.1	-2.1	83.1	-36.8

UNIT OF RESIDUALS (METERS)

NAD27(W) -TO- WN- 14 (MO'SKY MODEL)
****

SOLUTION FOR 3 TRANSLATION AND 1 SCALE PARAMETERS
(UNITS - METERS)

(USING VARIANCES ONLY)

DX METERS	DY METERS	DZ METERS	DL (X1.D+6)
-0.21741182D+02	0.13762186D+03	0.18177511D+03	0.74325854D+01

VARIANCE - COVARIANCE MATRIX

MO2= 0.30

0.52274800D+01	-0.26372589D-01	0.62720600D+00	0.21839138D-05
-0.26372589D-01	0.22504149D+01	-0.84692271D-02	-0.29489613D-07
0.62720600D+00	-0.84692271D-02	0.22661766D+01	0.70133660D-06
0.21839138D-05	-0.29489613D-07	0.70133660D-06	0.24420345D-11

COEFFICIENTS OF CORRELATION

0.10000000D+01	-0.76890960D-02	0.18222885D+00	0.61124231D+00
-0.76890960D-02	0.10000000D+01	-0.37502965D-02	-0.12579456D-01
0.18222885D+00	-0.37502965D-02	0.10000000D+01	0.29812866D+00
0.61124231D+00	-0.12579456D-01	0.29812866D+00	0.10000000D+01

Table 2.2-6a

Table 2.2-6a (cont.)

RESIDUALS V

	V1(NAD27(W))				V2(WN- 14)			V1 - V2		
1030	-0.9	0.5	1.3	1030	4.4	-1.8	-5.7	-5.2	2.3	7.0
3400	1.9	0.3	3.3	3400	-6.0	-1.7	-7.6	7.9	2.0	10.9
4280	0.2	-0.1	-1.2	4280	-1.1	0.3	5.5	1.3	-0.3	-6.7
6003	0.1	-0.2	-0.1	6003	-2.8	6.7	1.2	2.9	-6.9	-1.3
6134	0.3	-0.1	-0.7	6134	-3.0	1.2	6.5	3.3	-1.3	-7.2
7036	0.2	-0.1	-0.7	7036	-0.4	0.6	2.7	0.7	-0.8	-3.4
7045	-1.5	0.2	0.3	7045	3.2	-0.8	-1.0	-4.8	1.0	1.3
9001	-0.2	0.1	0.5	9001	2.5	-2.4	-5.3	-2.7	2.5	5.8

UNIT OF RESIDUALS (METERS)

Table 2.2-6b

NAD27(W) -TO- WN- 14 (MO'SKY MODEL)
****

SCALE FACTOR AND ROTATION PARAMETERS CONSTRAINED

SOLUTION FOR 3 TRANSLATION, 1 SCALE AND 3 ROTATION PARAMETERS

(USING VARIANCES ONLY)

DU METERS	DV METERS	DW METERS	DELTA (X1.D+6)	OMEGA SECONDS	PSI SECONDS	EPSILON SECONDS
-20.07	139.51	179.29	7.91	-0.21	-0.59	0.45

VARIANCE - COVARIANCE MATRIX

SQ2= 0.29

0.350D+01	0.278D+00	-0.387D+00	0.188D-06	-0.174D-06	-0.465D-06	0.261D-06
0.278D+00	0.357D+01	-0.520D+00	0.803D-08	-0.107D-05	-0.630D-06	0.893D-06
-0.387D+00	-0.520D+00	0.295D+01	0.549D-07	0.351D-06	0.996D-06	-0.421D-06
0.188D-06	0.803D-08	0.549D-07	0.207D-12	-0.639D-14	-0.580D-14	0.102D-13
-0.174D-06	-0.107D-05	0.351D-06	-0.639D-14	0.930D-12	0.395D-12	-0.382D-12
-0.465D-06	-0.630D-06	0.996D-06	-0.580D-14	0.395D-12	0.105D-11	-0.579D-12
0.261D-06	0.893D-06	-0.421D-06	0.102D-13	-0.382D-12	-0.579D-12	0.123D-11

COEFFICIENTS OF CORRELATION

0.100D+01	0.787D-01	-0.120D+00	0.220D+00	-0.966D-01	-0.242D+00	0.126D+00
0.787D-01	0.100D+01	-0.160D+00	0.933D-02	-0.586D+00	-0.325D+00	0.426D+00
-0.120D+00	-0.160D+00	0.100D+01	0.702D-01	0.212D+00	0.565D+00	-0.221D+00
0.220D+00	0.933D-02	0.702D-01	0.100D+01	-0.146D-01	-0.124D-01	0.201D-01
-0.966D-01	-0.586D+00	0.212D+00	-0.146D-01	0.100D+01	0.400D+00	-0.356D+00
-0.242D+00	-0.325D+00	0.565D+00	-0.124D-01	0.400D+00	0.100D+01	-0.508D+00
0.126D+00	0.426D+00	-0.221D+00	0.201D-01	-0.356D+00	-0.508D+00	0.100D+01

Table 2.2-6b(cont.)

RESIDUALS V

	V1(NAD27(W))				V2(WN- 14)			V1 - V2		
1030	-0.9	0.4	1.6	1030	4.6	-1.5	-6.9	-5.5	2.0	8.5
3400	2.2	0.5	3.0	3400	-6.9	-2.9	-6.8	9.2	3.4	9.8
4280	0.1	-0.2	-0.9	4280	-0.5	0.9	3.8	0.6	-1.1	-4.7
6003	0.2	-0.1	-0.2	6003	-4.5	4.3	1.7	4.7	-4.4	-1.9
6134	0.2	-0.2	-0.6	6134	-2.5	1.8	4.9	2.7	-2.0	-5.5
7036	-0.1	-0.4	-1.0	7036	0.2	1.6	3.6	-0.4	-2.0	-4.5
7045	-1.1	0.5	0.0	7045	2.3	-2.0	-0.0	-3.4	2.5	0.0
9001	-0.2	0.1	0.5	9001	2.7	-2.0	-5.4	-2.9	2.2	5.9

UNIT OF RESIDUALS (METERS)

NAD27(E) -TO- WN- 14 (MOLSKY MODEL)
****

SOLUTION FOR 3 TRANSLATION AND 1 SCALE PARAMETERS
(UNITS - METERS)

(USING VARIANCES ONLY)

DX METERS	DY METERS	DZ METERS	DL (X1.D+6)
-0.30339362D+02	0.14945917D+03	0.17472266D+03	-0.21285982D+01

VARIANCE - COVARIANCE MATRIX

MO2= 0.95

0.92906337D+01	-0.86245681D+00	-0.12223337D+01	-0.43665589D-05
-0.86245681D+00	0.26728499D+01	0.16169914D+00	0.57763998D-06
-0.12223337D+01	0.16169914D+00	0.27615054D+01	0.81867152D-06
-0.43665589D-05	0.57763998D-06	0.81867152D-06	0.29245511D-11

COEFFICIENTS OF CORRELATION

0.10000000D+01	-0.17307224D+00	-0.24132048D+00	-0.83769718D+00
-0.17307224D+00	0.10000000D+01	0.59517883D-01	0.20660477D+00
-0.24132048D+00	0.59517883D-01	0.10000000D+01	0.28807603D+00
-0.83769718D+00	0.20660477D+00	0.28807603D+00	0.10000000D+01

Table 2.2-7a

Table 2.2-7a (cont.)

RESIDUALS V

V1(NAD27(E))				V2(WN- 14)				V1 - V2		
1021	0.8	0.1	1.2	1021	-3.1	-0.3	-3.5	3.9	0.4	4.7
1022	-0.4	0.5	0.8	1022	1.9	-2.8	-3.9	-2.3	3.3	4.7
1034	-1.9	3.4	0.2	1034	3.5	-10.2	-0.5	-5.3	13.7	0.7
1042	2.2	0.5	1.0	1042	-6.6	-1.7	-3.0	8.8	2.2	4.0
3401	2.2	-1.3	-1.4	3401	-9.0	4.9	4.0	11.1	-6.2	-5.3
3402	-0.4	-0.0	0.8	3402	0.6	0.1	-1.9	-0.9	-0.2	2.7
3648	-1.7	0.2	1.7	3648	3.8	-1.0	-3.2	-5.5	1.2	4.9
3657	2.3	0.4	-0.5	3657	-8.2	-1.7	1.5	10.5	2.1	-2.0
3861	-2.1	-0.9	0.3	3861	6.8	4.1	-1.2	-8.9	-5.0	1.5
6002	-0.0	-0.6	-1.0	6002	0.3	6.4	7.0	-0.3	-7.0	-8.0
7043	-0.0	-0.6	-1.0	7043	0.3	6.5	6.9	-0.3	-7.1	-7.9
7072	0.2	0.1	0.6	7072	-1.7	-1.7	-6.5	1.9	1.8	7.1
7075	-2.4	-0.4	-0.7	7075	5.5	1.3	2.2	-7.9	-1.7	-2.9

UNIT OF RESIDUALS (METERS)

Table 2.2-7b

NAD27(E) -TO- WN- 14 (MO'SKY MODEL)
****

SCALE FACTOR AND ROTATION PARAMETERS CONSTRAINED

SOLUTION FOR 3 TRANSLATION, 1 SCALE AND 3 ROTATION PARAMETERS

(USING VARIANCES ONLY)

DU METERS	DV METERS	DW METERS	DELTA (X1.D+6)	OMEGA SECONDS	PSI SECONDS	EPSILON SECONDS
-30.98	140.97	174.93	-2.15	-1.01	0.01	-0.54

VARIANCE - COVARIANCE MATRIX

SD2= 0.76

0.311D+01	-0.113D+00	0.392D-01	-0.566D-06	-0.258D-08	-0.127D-06	0.628D-08
-0.113D+00	0.404D+01	-0.871D+00	0.770D-07	0.128D-05	0.571D-06	0.210D-07
0.392D-01	-0.871D+00	0.355D+01	0.109D-06	-0.598D-06	-0.956D-06	0.505D-07
-0.566D-06	0.770D-07	0.109D-06	0.379D-12	0.130D-14	-0.194D-14	0.207D-15
-0.258D-08	0.128D-05	-0.598D-06	0.130D-14	0.866D-12	0.392D-12	-0.101D-12
-0.127D-06	0.571D-06	-0.956D-06	-0.194D-14	0.392D-12	0.618D-12	-0.676D-13
0.628D-08	0.210D-07	0.505D-07	0.207D-15	-0.101D-12	-0.676D-13	0.462D-12

COEFFICIENTS OF CORRELATION

0.100D+01	-0.320D-01	0.118D-01	-0.521D+00	-0.157D-02	-0.918D-01	0.524D-02
-0.320D-01	0.100D+01	-0.230D+00	0.622D-01	0.686D+00	0.362D+00	0.154D-01
0.118D-01	-0.230D+00	0.100D+01	0.941D-01	-0.341D+00	-0.645D+00	0.395D-01
-0.521D+00	0.622D-01	0.941D-01	0.100D+01	0.227D-02	-0.400D-02	0.495D-03
-0.157D-02	0.686D+00	-0.341D+00	0.227D-02	0.100D+01	0.535D+00	-0.159D+00
-0.918D-01	0.362D+00	-0.645D+00	-0.400D-02	0.535D+00	0.100D+01	-0.126D+00
0.524D-02	0.154D-01	0.395D-01	0.495D-03	-0.159D+00	-0.126D+00	0.100D+01

Table 2.2-7b (cont.)

RESIDUALS V

	V1(NAD27(E))				V2(WN- 14)			V1 - V2		
1021	0.6	0.2	1.3	1021	-2.5	-1.0	-3.8	3.1	1.2	5.1
1022	0.1	0.8	0.5	1022	-0.7	-4.7	-2.5	0.8	5.5	3.0
1034	-3.2	1.1	0.6	1034	6.0	-3.2	-2.0	-9.2	4.3	2.6
1042	2.4	0.3	0.9	1042	-7.2	-1.1	-2.7	9.6	1.5	3.6
3401	1.6	-0.9	-1.0	3401	-6.7	3.5	2.9	8.3	-4.4	-3.8
3402	0.5	-0.5	0.4	3402	-0.8	1.7	-1.0	1.4	-2.2	1.4
3648	-1.2	0.4	1.4	3648	2.7	-1.7	-2.6	-3.9	2.1	4.1
3657	2.0	0.6	-0.4	3657	-7.3	-2.4	1.0	9.3	3.0	-1.4
3861	-1.3	-0.3	-0.0	3861	4.3	1.5	0.2	-5.7	-1.8	-0.2
6002	-0.1	-0.6	-0.9	6002	1.1	5.8	6.6	-1.3	-6.3	-7.5
7043	-0.2	-0.6	-0.9	7043	1.1	5.8	6.5	-1.3	-6.4	-7.4
7072	0.4	0.4	0.5	7072	-4.4	-4.4	-5.1	4.8	4.7	5.5
7075	-3.4	-1.2	-0.3	7075	7.9	3.5	0.9	-11.3	-4.8	-1.2

UNIT OF RESIDUALS (METERS)

Table 2.2-8a

NAD-27 -TO- WN- 14 (MO'SKY MODEL)
****

SOLUTION FOR 3 TRANSLATION AND 1 SCALE PARAMETERS
(UNITS - METERS)

(USING VARIANCES ONLY)

DX METERS	DY METERS	DZ METERS	DL (XI.D+6)
-0.31386640D+02	0.14649403D+03	0.17623487D+03	-0.10563358D+01

VARIANCE - COVARIANCE MATRIX

MD2= 1.10

0.37743307D+01	-0.17787074D+00	-0.35375226D+00	-0.12545693D-05
-0.17787074D+00	0.22089805D+01	0.50859988D-01	0.18037307D-06
-0.35375226D+00	0.50859988D-01	0.22178297D+01	0.35872893D-06
-0.12545693D-05	0.18037307D-06	0.35872893D-06	0.12722189D-11

COEFFICIENTS OF CORRELATION

0.10000000D+01	-0.61601118D-01	-0.12226866D+00	-0.57252410D+00
-0.61601118D-01	0.10000000D+01	0.22978211D-01	0.10759568D+00
-0.12226866D+00	0.22978211D-01	0.10000000D+01	0.21356073D+00
-0.57252410D+00	0.10759568D+00	0.21356073D+00	0.10000000D+01

Table 2.2-8a (cont.)

RESIDUALS V

	V1(NAD-27)				V2(WN- 14)			V1 - V2		
1021	1.0	-0.5	1.5	1021	-3.8	2.0	-4.6	4.8	-2.5	6.1
1022	-0.3	-0.1	0.9	1022	1.4	0.4	-4.1	-1.7	-0.5	4.9
1030	-0.2	2.1	0.8	1030	0.9	-7.0	-3.6	-1.1	9.1	4.4
1034	-2.2	2.9	0.7	1034	4.0	-8.5	-2.3	-6.2	11.4	3.0
1042	2.3	-0.2	1.3	1042	-7.0	0.8	-3.8	9.3	-1.1	5.2
3400	0.7	1.5	1.7	3400	-2.1	-8.6	-3.8	2.8	10.1	5.5
3401	2.4	-1.8	-0.9	3401	-10.1	6.9	2.6	12.5	-8.7	-3.5
3402	-0.4	-0.9	1.0	3402	0.6	2.9	-2.4	-1.0	-3.8	3.4
3648	-1.5	-0.4	2.0	3648	3.4	1.8	-3.7	-4.9	-2.3	5.8
3657	2.5	-0.2	-0.1	3657	-9.0	0.6	0.3	11.5	-0.7	-0.5
3861	-1.9	-1.6	0.4	3861	6.2	7.2	-1.3	-8.2	-8.8	1.7
4280	1.4	0.9	-1.6	4280	-6.8	-4.5	7.2	8.1	5.4	-8.8
6002	0.1	-0.9	-0.8	6002	-0.6	9.1	5.7	0.7	-9.9	-6.5
6003	0.2	-0.2	-1.4	6003	-4.9	7.2	10.9	5.1	-7.4	-12.3
6134	0.7	0.5	-0.9	6134	-7.5	-5.2	8.2	8.2	5.7	-9.1
7036	-2.7	2.7	0.3	7036	5.5	-11.9	-0.9	-8.2	14.6	1.2
7043	0.1	-0.9	-0.8	7043	-0.6	9.1	5.6	0.6	-10.0	-6.4
7045	-3.3	1.9	-1.1	7045	6.9	-6.8	3.5	-10.1	8.7	-4.5
7072	0.2	-0.1	0.6	7072	-2.5	1.7	-6.7	2.7	-1.9	7.4
7075	-2.2	-1.1	-0.2	7075	5.2	3.1	0.6	-7.4	-4.1	-0.8
9001	-0.4	0.7	0.5	9001	5.2	-13.0	-5.0	-5.5	13.7	5.5

UNIT OF RESIDUALS (METERS)

Table 2.2-8b

NAD-27 -TO- WN- 14 (MOLSKY MODEL)
****

SCALE FACTOR AND ROTATION PARAMETERS CONSTRAINED

SOLUTION FOR 3 TRANSLATION, 1 SCALE AND 3 ROTATION PARAMETERS

(USING VARIANCES ONLY)

DU METERS	DV METERS	DW METERS	DELTA (X1.D+6)	OMEGA SECONDS	PSI SECONDS	EPSILON SECONDS
-31.71	142.34	177.32	-0.80	-0.86	-0.23	-0.33

VARIANCE - COVARIANCE MATRIX

SD2= 0.76

0.182D+01	-0.258D-02	-0.280D-02	-0.724D-07	0.521D-08	-0.216D-07	0.823D-08
-0.258D-02	0.159D+01	0.154D-02	0.103D-07	0.624D-07	-0.318D-08	0.856D-07
-0.280D-02	0.154D-02	0.151D+01	0.207D-07	-0.757D-08	-0.565D-07	0.131D-07
-0.724D-07	0.103D-07	0.207D-07	0.734D-13	-0.200D-15	0.191D-16	0.262D-15
0.521D-08	0.624D-07	-0.757D-08	-0.200D-15	0.771D-13	0.959D-14	-0.100D-13
-0.216D-07	-0.318D-08	-0.565D-07	0.191D-16	0.959D-14	0.695D-13	-0.293D-13
0.823D-08	0.856D-07	0.131D-07	0.262D-15	-0.100D-13	-0.293D-13	0.242D-12

COEFFICIENTS OF CORRELATION

0.100D+01	-0.151D-02	-0.169D-02	-0.198D+00	0.139D-01	-0.607D-01	0.124D-01
-0.151D-02	0.100D+01	0.992D-03	0.302D-01	0.178D+00	-0.956D-02	0.138D+00
-0.169D-02	0.992D-03	0.100D+01	0.621D-01	-0.222D-01	-0.174D+00	0.217D-01
-0.198D+00	0.302D-01	0.621D-01	0.100D+01	-0.266D-02	0.267D-03	0.197D-02
0.139D-01	0.178D+00	-0.222D-01	-0.266D-02	0.100D+01	0.131D+00	-0.734D-01
-0.607D-01	-0.956D-02	-0.174D+00	0.267D-03	0.131D+00	0.100D+01	-0.226D+00
0.124D-01	0.138D+00	0.217D-01	0.197D-02	-0.734D-01	-0.226D+00	0.100D+01

Table 2.2-8b (cont.)

RESIDUALS V

V1(NAD-27)				V2(WN- 14)				V1 - V2		
1021	1.0	0.2	1.3	1021	-3.9	-0.9	-3.8	4.8	1.1	5.1
1022	0.0	0.5	0.5	1022	-0.1	-3.0	-2.3	0.2	3.5	2.8
1030	-0.5	-0.3	1.4	1030	2.7	0.9	-6.2	-3.2	-1.2	7.6
1034	-2.9	1.8	1.2	1034	5.4	-5.4	-3.9	-8.3	7.1	5.0
1042	2.5	0.2	1.1	1042	-7.6	-0.8	-3.1	10.1	1.0	4.1
3400	0.5	0.6	2.2	3400	-1.5	-3.2	-5.1	2.0	3.8	7.4
3401	2.2	-0.8	-1.1	3401	-9.1	3.1	3.1	11.3	-3.9	-4.2
3402	0.2	-0.7	0.7	3402	-0.3	2.4	-1.6	0.5	-3.1	2.3
3648	-1.1	0.2	1.5	3648	2.5	-0.8	-2.7	-3.6	1.0	4.2
3657	2.5	0.6	-0.4	3657	-8.8	-2.4	1.0	11.3	3.1	-1.4
3861	-1.5	-0.8	-0.2	3861	4.7	3.4	0.6	-6.2	-4.1	-0.8
4280	0.9	-1.0	-0.9	4280	-4.4	5.1	4.1	5.3	-6.1	-5.1
6002	0.1	-0.6	-0.9	6002	-0.5	5.8	6.5	0.5	-6.3	-7.4
6003	0.0	-0.5	-0.9	6003	-0.5	17.5	6.9	0.6	-18.1	-7.7
6134	0.5	-0.4	-0.6	6134	-5.5	4.5	5.2	6.0	-4.9	-5.8
7036	-2.2	2.2	0.2	7036	4.5	-9.6	-0.7	-6.7	11.7	0.9
7043	0.1	-0.6	-0.9	7043	-0.5	5.8	6.4	0.5	-6.4	-7.3
7045	-3.6	0.5	-0.6	7045	7.5	-1.9	2.0	-11.1	2.5	-2.6
7072	0.4	0.2	0.4	7072	-4.1	-2.5	-4.7	4.5	2.7	5.1
7075	-2.7	-0.8	-0.1	7075	6.3	2.3	0.2	-9.0	-3.1	-0.3
9001	-0.4	0.4	0.6	9001	5.2	-6.8	-6.2	-5.6	7.1	6.8

UNIT OF RESIDUALS (METERS)

Table 2.2-9

NAD-27 -TO- WN- 14 (VEIS MODEL)

****

SOLUTION FOR 3 TRANSLATION, 1 SCALE AND 3 ROTATION PARAMETERS

(USING VARIANCES ONLY)

DU METERS	DV METERS	DW METERS	DELTA (X1.D+6)	ALPHA SECONDS	KSI SECONDS	ETA SECONDS
-31.57	142.07	177.28	-0.96	-0.35	-0.34	0.87

VARIANCE - COVARIANCE MATRIX

SO2= 0.83

0.294D+01	-0.397D-01	-0.489D-01	-0.950D-06	0.251D-06	0.948D-07	0.952D-07
-0.397D-01	0.270D+01	-0.484D-02	0.125D-06	0.381D-06	0.955D-06	-0.683D-06
-0.489D-01	-0.484D-02	0.224D+01	0.267D-06	0.440D-06	0.258D-06	0.514D-06
-0.950D-06	0.125D-06	0.267D-06	0.959D-12	-0.250D-13	0.363D-13	0.182D-13
0.251D-06	0.381D-06	0.440D-06	-0.250D-13	0.751D-12	-0.793D-13	-0.573D-13
0.948D-07	0.955D-06	0.258D-06	0.363D-13	-0.793D-13	0.284D-11	0.151D-12
0.952D-07	-0.683D-06	0.514D-06	0.182D-13	-0.573D-13	0.151D-12	0.102D-11

COEFFICIENTS OF CORRELATION

0.100D+01	-0.141D-01	-0.191D-01	-0.565D+00	0.169D+00	0.328D-01	0.550D-01
-0.141D-01	0.100D+01	-0.197D-02	0.775D-01	0.268D+00	0.345D+00	-0.412D+00
-0.191D-01	-0.197D-02	0.100D+01	0.182D+00	0.339D+00	0.102D+00	0.341D+00
-0.565D+00	0.775D-01	0.182D+00	0.100D+01	-0.295D-01	0.220D-01	0.184D-01
0.169D+00	0.268D+00	0.339D+00	-0.295D-01	0.100D+01	-0.543D-01	-0.655D-01
0.328D-01	0.345D+00	0.102D+00	0.220D-01	-0.543D-01	0.100D+01	0.888D-01
0.550D-01	-0.412D+00	0.341D+00	0.184D-01	-0.655D-01	0.888D-01	0.100D+01

NOTE : THE POSITIVE ROTATIONS ARE TOWARDS SOUTH, EAST, AND ALONG ELLIPSOIDAL NORMAL UPWARDS.

Table 2.2-9 (cont.)

RESIDUALS V

V1(NAD-27)				V2(WN- 14)				V1 - V2		
1021	0.9	0.2	1.3	1021	-3.7	-1.0	-3.8	4.6	1.2	5.1
1022	0.0	0.6	0.5	1022	-0.2	-3.3	-2.3	0.2	3.9	2.8
1030	-0.5	-0.4	1.5	1030	2.4	1.3	-6.2	-2.9	-1.7	7.7
1034	-2.9	1.7	1.2	1034	5.4	-5.0	-3.9	-8.4	6.7	5.0
1042	2.5	0.3	1.1	1042	-7.5	-0.9	-3.0	10.1	1.1	4.1
3400	0.5	0.5	2.2	3400	-1.6	-2.9	-5.1	2.2	3.4	7.3
3401	2.1	-0.8	-1.1	3401	-8.8	3.0	3.1	11.0	-3.8	-4.2
3402	0.2	-0.7	0.7	3402	-0.4	2.2	-1.6	0.6	-2.9	2.3
3648	-1.1	0.2	1.5	3648	2.6	-1.0	-2.7	-3.7	1.3	4.2
3657	2.4	0.6	-0.4	3657	-8.6	-2.5	1.0	11.1	3.1	-1.4
3861	-1.5	-0.7	-0.2	3861	4.7	3.0	0.6	-6.2	-3.7	-0.8
4280	1.0	-1.1	-0.9	4280	-4.7	5.6	4.0	5.7	-6.7	-5.0
6002	0.0	-0.5	-0.9	6002	-0.3	5.7	6.5	0.4	-6.2	-7.5
6003	0.0	-0.6	-0.9	6003	-0.7	18.4	6.8	0.7	-18.9	-7.6
6134	0.5	-0.5	-0.6	6134	-5.8	4.9	5.2	6.4	-5.4	-5.8
7036	-2.1	2.2	0.2	7036	4.3	-9.6	-0.7	-6.4	11.8	0.8
7043	0.0	-0.6	-0.9	7043	-0.3	5.8	6.4	0.3	-6.3	-7.4
7045	-3.5	0.5	-0.6	7045	7.4	-1.6	2.0	-10.9	2.1	-2.6
7072	0.4	0.2	0.4	7072	-4.1	-2.9	-4.7	4.5	3.1	5.1
7075	-2.8	-0.9	-0.1	7075	6.4	2.5	0.2	-9.2	-3.4	-0.3
9001	-0.3	0.4	0.6	9001	4.9	-6.6	-6.2	-5.3	6.9	6.8

UNIT OF RESIDUALS (METERS)

SAD-69 -TO- WN- 14 (MO'SKY MODEL)
****

SOLUTION FOR 3 TRANSLATION AND 1 SCALE PARAMETERS
(UNITS - METERS)

(USING VARIANCES ONLY)

DX METERS	DY METERS	DZ METERS	DL (X1.D+6)
-0.97738228D+02	-0.94933264D+01	-0.28031740D+02	-0.66826081D+01

VARIANCE - COVARIANCE MATRIX

MO2= 1.10

0.11948963D+02	0.15292699D+01	-0.26596853D+01	0.22855727D-05
0.15292699D+01	0.95314364D+01	-0.15037709D+01	0.12922498D-05
-0.26596853D+01	-0.15037709D+01	0.12732530D+02	-0.22474631D-05
0.22855727D-05	0.12922498D-05	-0.22474631D-05	0.19313339D-11

COEFFICIENTS OF CORRELATION

0.10000000D+01	0.14329791D+00	-0.21562930D+00	0.47577459D+00
0.14329791D+00	0.10000000D+01	-0.13650393D+00	0.30118865D+00
-0.21562930D+00	-0.13650393D+00	0.10000000D+01	-0.45321736D+00
0.47577459D+00	0.30118865D+00	-0.45321736D+00	0.10000000D+01

Table 2.2-10a

Table 2.2-10a (cont.)

RESIDUALS V

V1(SAD-69)				V2(WN- 14)				V1 - V2		
3414	3.3	1.3	7.2	3414	-1.4	-0.9	-3.4	4.7	2.2	10.6
3431	-0.7	3.1	0.3	3431	0.8	-4.7	-0.2	-1.5	7.9	0.5
3477	17.3	0.6	13.0	3477	-10.7	-0.9	-9.1	28.0	1.5	22.2
6008	-0.1	0.4	2.0	6008	0.7	-6.4	-15.1	-0.8	6.8	17.1
6009	-1.6	-1.8	-2.3	6009	7.8	9.9	8.7	-9.4	-11.7	-11.0
6019	-0.0	-0.3	-0.9	6019	0.4	2.4	4.0	-0.4	-2.7	-4.9
6067	-0.5	-0.1	-0.5	6067	7.4	0.9	5.1	-7.9	-1.0	-5.6
9007	1.3	0.1	-1.4	9007	-13.1	-0.8	4.8	14.4	0.9	-6.2
9009	-0.5	-0.2	-2.1	9009	5.6	2.4	11.6	-6.1	-2.6	-13.7
9031	-5.1	0.7	1.9	9031	4.7	-0.6	-1.0	-9.8	1.4	2.9

UNIT OF RESIDUALS (METERS)

Table 2.2-10b

SAD-69 -TO- WN- 14 (MO'SKY MODEL)
****

SCALE FACTOR AND ROTATION PARAMETERS CONSTRAINED

SOLUTION FOR 3 TRANSLATION, 1 SCALE AND 3 ROTATION PARAMETERS

(USING VARIANCES ONLY)

DU METERS	DV METERS	DW METERS	DELTA (X1.D+6)	OMEGA SECONDS	PSI SECONDS	EPSILON SECONDS
-96.57	-13.67	-29.36	-6.67	0.63	-0.17	0.12

VARIANCE - COVARIANCE MATRIX

SD2= 0.97

0.915D+01	-0.172D+00	-0.202D+00	0.419D-06	0.325D-06	0.291D-06	0.674D-07
-0.172D+00	0.912D+01	0.697D-01	0.231D-06	-0.769D-06	0.579D-07	-0.409D-06
-0.202D+00	0.697D-01	0.989D+01	-0.410D-06	-0.122D-06	0.346D-06	-0.185D-06
0.419D-06	0.231D-06	-0.410D-06	0.352D-12	0.128D-14	0.159D-14	0.252D-14
0.325D-06	-0.769D-06	-0.122D-06	0.128D-14	0.657D-12	-0.103D-12	0.463D-14
0.291D-06	0.579D-07	0.346D-06	0.159D-14	-0.103D-12	0.340D-12	0.585D-13
0.674D-07	-0.409D-06	-0.185D-06	0.252D-14	0.463D-14	0.585D-13	0.373D-12

COEFFICIENTS OF CORRELATION

0.100D+01	-0.188D-01	-0.212D-01	0.234D+00	0.133D+00	0.165D+00	0.365D-01
-0.188D-01	0.100D+01	0.734D-02	0.129D+00	-0.314D+00	0.329D-01	-0.222D+00
-0.212D-01	0.734D-02	0.100D+01	-0.219D+00	-0.479D-01	0.189D+00	-0.965D-01
0.234D+00	0.129D+00	-0.219D+00	0.100D+01	0.266D-02	0.458D-02	0.696D-02
0.133D+00	-0.314D+00	-0.479D-01	0.266D-02	0.100D+01	-0.219D+00	0.934D-02
0.165D+00	0.329D-01	0.189D+00	0.458D-02	-0.219D+00	0.100D+01	0.164D+00
0.365D-01	-0.222D+00	-0.965D-01	0.696D-02	0.934D-02	0.164D+00	0.100D+01

Table 2.2-10b (cont.)

RESIDUALS V

V1(SAD-69)				V2(WN- 14)				V1 - V2		
3414	4.1	-1.3	6.3	3414	-1.8	0.8	-3.0	5.9	-2.1	9.2
3431	-1.0	2.5	0.1	3431	1.1	-3.7	-0.1	-2.0	6.2	0.2
3477	16.3	2.3	13.9	3477	-10.1	-3.4	-9.8	26.3	5.8	23.7
6008	0.0	0.3	2.0	6008	-0.3	-5.1	-14.6	0.4	5.4	16.6
6009	-2.0	-1.0	-1.9	6009	9.9	5.4	7.1	-11.9	-6.4	-9.0
6019	-0.1	-0.2	-0.8	6019	1.5	2.1	3.8	-1.6	-2.3	-4.6
6067	-0.2	-0.5	-0.8	6067	2.8	7.4	7.5	-3.0	-7.9	-8.3
9007	1.0	0.4	-1.2	9007	-10.7	-2.9	3.9	11.8	3.3	-5.1
9009	-0.5	0.0	-1.9	9009	5.8	-0.6	10.8	-6.3	0.6	-12.8
9031	-5.0	1.6	2.2	9031	4.6	-1.3	-1.1	-9.6	2.9	3.3

UNIT OF RESIDUALS (METERS)

Table 2.2-11

SAD-69 -TO- WN- 14 (VEIS MODEL)
****

SOLUTION FOR 3 TRANSLATION, 1 SCALE AND 3 ROTATION PARAMETERS

(USING VARIANCES ONLY)

DU METERS	DV METERS	DW METERS	DELTA (X1.D+6)	ALPHA SECONDS	KSI SECONDS	ETA SECONDS
-97.06	-13.39	-29.77	-6.66	0.04	-0.08	-0.64

VARIANCE - COVARIANCE MATRIX

SO2= 1.13

0.160D+02	-0.163D+01	-0.865D+00	0.243D-05	-0.185D-05	0.182D-05	-0.173D-05
-0.163D+01	0.186D+02	0.810D+00	0.119D-05	-0.257D-06	-0.192D-05	0.546D-05
-0.865D+00	0.810D+00	0.165D+02	-0.231D-05	-0.217D-05	0.502D-06	0.159D-05
0.243D-05	0.119D-05	-0.231D-05	0.198D-11	0.252D-14	0.101D-12	-0.446D-13
-0.185D-05	-0.257D-06	-0.217D-05	0.252D-14	0.198D-11	0.259D-12	0.390D-12
0.182D-05	-0.192D-05	0.502D-06	0.101D-12	0.259D-12	0.296D-11	0.358D-12
-0.173D-05	0.546D-05	0.159D-05	-0.446D-13	0.390D-12	0.358D-12	0.439D-11

COEFFICIENTS OF CORRELATION

0.100D+01	-0.946D-01	-0.531D-01	0.432D+00	-0.328D+00	0.264D+00	-0.207D+00
-0.946D-01	0.100D+01	0.462D-01	0.195D+00	-0.423D-01	-0.259D+00	0.603D+00
-0.531D-01	0.462D-01	0.100D+01	-0.403D+00	-0.379D+00	0.719D-01	0.187D+00
0.432D+00	0.195D+00	-0.403D+00	0.100D+01	0.127D-02	0.418D-01	-0.151D-01
-0.328D+00	-0.423D-01	-0.379D+00	0.127D-02	0.100D+01	0.107D+00	0.132D+00
0.264D+00	-0.259D+00	0.719D-01	0.418D-01	0.107D+00	0.100D+01	0.993D-01
-0.207D+00	0.603D+00	0.187D+00	-0.151D-01	0.132D+00	0.993D-01	0.100D+01

NOTE : THE POSITIVE ROTATIONS ARE TOWARDS SOUTH, EAST, AND ALONG ELLIPSOIDAL NORMAL UPWARDS.

Table 2.2-11 (cont.)

RESIDUALS V

V1(SAD-69)				V2(WN- 14)				V1 - V2		
3414	3.9	-1.1	6.0	3414	-1.7	0.7	-2.8	5.6	-1.8	8.8
3431	-1.3	2.5	0.0	3431	1.4	-3.8	-0.0	-2.7	6.3	0.1
3477	16.8	2.2	14.1	3477	-10.3	-3.2	-9.9	27.1	5.5	24.1
6008	0.1	0.3	1.9	6008	-1.0	-5.1	-14.4	1.0	5.4	16.3
6009	-1.9	-1.0	-1.8	6009	9.5	5.7	6.7	-11.3	-6.7	-8.5
6019	-0.2	-0.2	-0.8	6019	2.3	2.0	3.6	-2.5	-2.3	-4.4
6067	-0.2	-0.5	-0.9	6067	2.9	7.0	8.2	-3.1	-7.5	-9.1
9007	1.0	0.4	-1.1	9007	-10.6	-2.8	3.7	11.6	3.1	-4.8
9009	-0.4	0.0	-1.9	9009	4.8	-0.4	10.6	-5.3	0.4	-12.5
9031	-5.7	1.6	2.4	9031	5.3	-1.3	-1.3	-11.0	2.9	3.7

UNIT OF RESIDUALS (METERS)

Table 2.2-12

Summary of Datum Transformations to WN-14 System

Transformation Model	Datum	Australian National 4 Parameters	Australian National 7 Parameters	ED-50 4 Parameters	ED-50 7 Parameters	NAD-27 4 Parameters	NAD-27 7 Parameters	SAD-69 4 Parameters	SAD-69 7 Parameters
Molodensky's	Δu	-154.3±5.0	-157.0±1.8	-99.4±4.4	-99.4±4.4	-31.4±1.9	-31.7±1.4	-97.7±3.5	-96.6±3.0
	Δv	-59.5±5.0	-59.1±1.8	-133.2±4.6	-132.0±4.5	146.5±1.5	142.3±1.3	-9.5±3.1	-13.7±3.0
	Δw	132.3±5.5	131.2±2.0	-116.7±4.5	-116.0±4.3	176.2±1.5	177.3±1.2	-28.0±3.6	-29.4±3.2
	Δ	0.92±2.91	1.20±0.71	6.07±2.74	6.75±0.84	-1.06±1.13	-0.80±0.27	-6.68±1.39	-6.67±0.59
	$*10^8$								
	ω''		-1.03±0.18		0.31±0.21		-0.86±0.06		0.63±0.17
	ψ''		-0.99±0.18		-0.14±0.32		-0.23±0.05		-0.17±0.12
	ϵ''		0.25±0.22		0.48±0.23		-0.33±0.10		0.12±0.13
Veis'	Δu		-157.0±3.2		-99.4±5.0		-31.6±1.7		-97.1±4.0
	Δv		-59.2±3.2		-132.2±5.0		142.1±1.6		-13.4±4.3
	Δw		131.2±3.6		-116.4±4.8		177.3±1.5		-29.8±4.1
	Δ		1.14±1.83		6.06±2.83		-0.96±0.98		-6.66±1.41
	$*10^8$								
	α''		-0.35±0.38		0.30±0.65		-0.35±0.18		0.04±0.29
	ξ''		0.47±0.64		-0.13±0.98		-0.34±0.35		-0.08±0.35
	η''		1.32±0.52		0.26±0.70		0.87±0.21		-0.64±0.43

2.3 Determination of Network Distortions

An empirical way to study possible distortions in the various geodetic networks is under study, by plotting the residuals ($\delta\lambda$, $\delta\varphi$, δh) of the transformation between the OSU275 system and the geodetic system in question. Fig. 2.3-1 presents the general flow chart of the procedure. The Molodensky (4 and 7 parameter transformations) as well as the Vanicek models are being considered.

Figures 2.3-2, 3, and 4 show a sample for the NAD. At this moment comparisons between distortions from different transformations and residuals are under investigation, while a more detailed paper is under preparation.

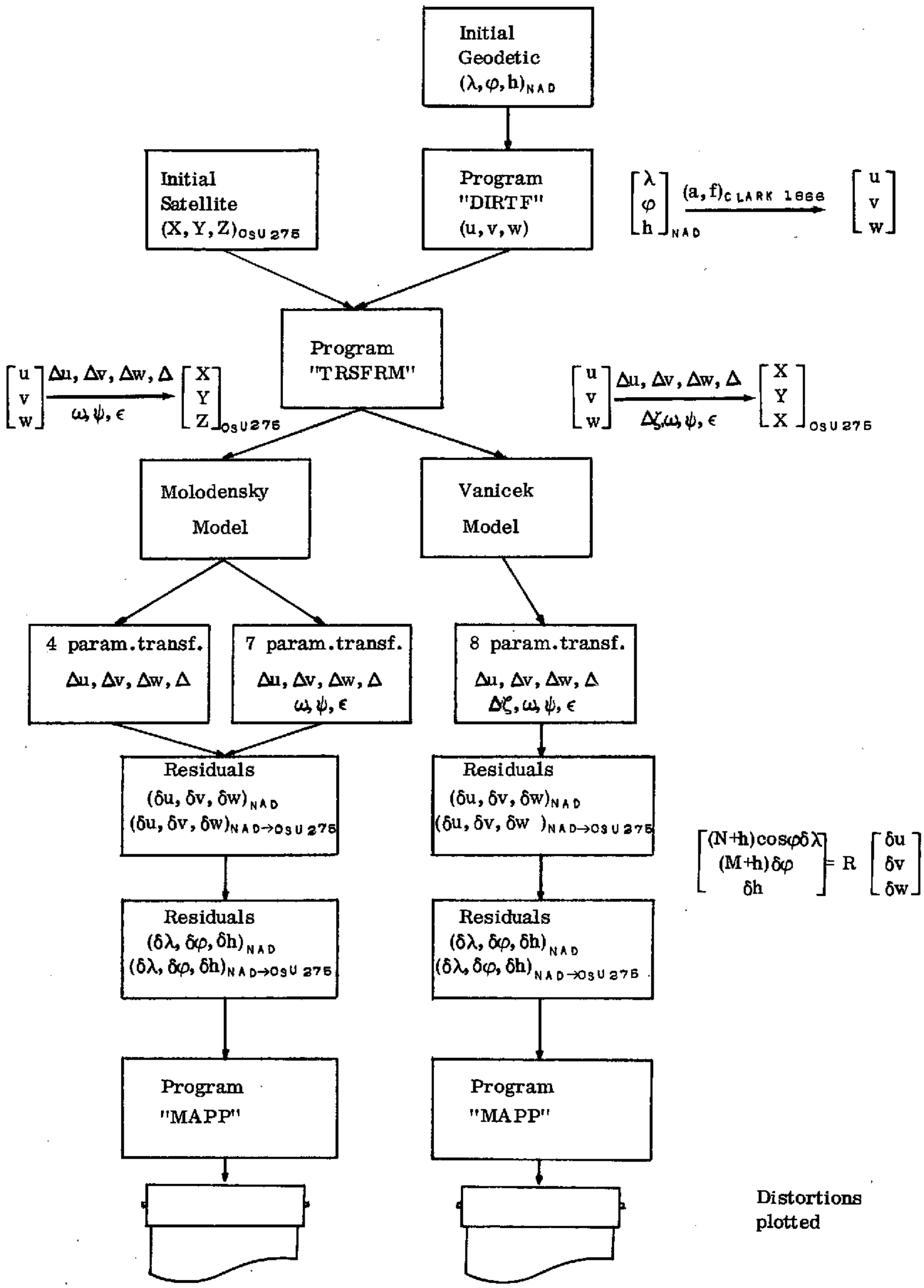


Fig. 2.3-1 Flow Chart for Distortion Investigation

Fig. 2.3-2 Distortion of λ

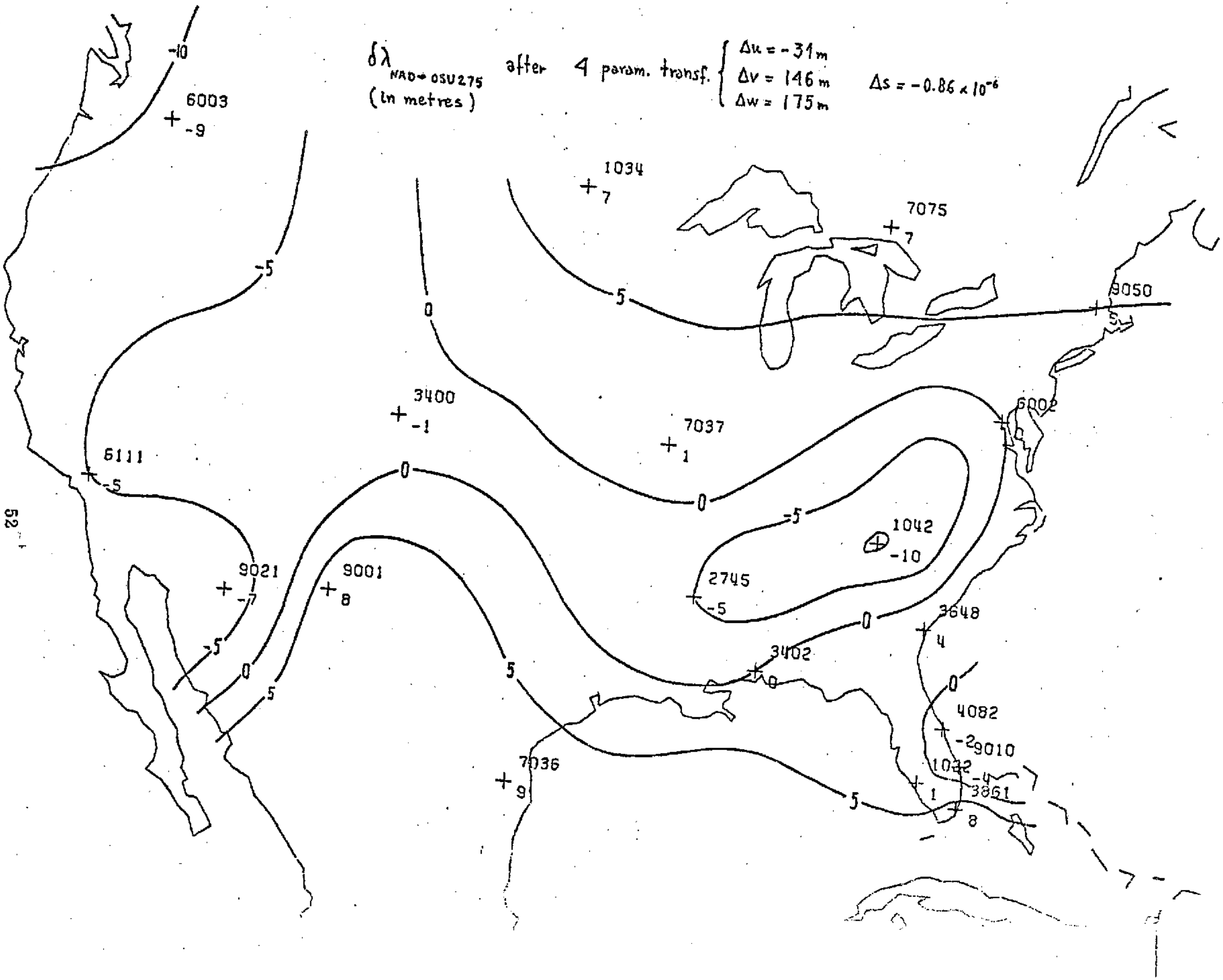


Fig. 2.3-3 Distortions of φ in the NAD

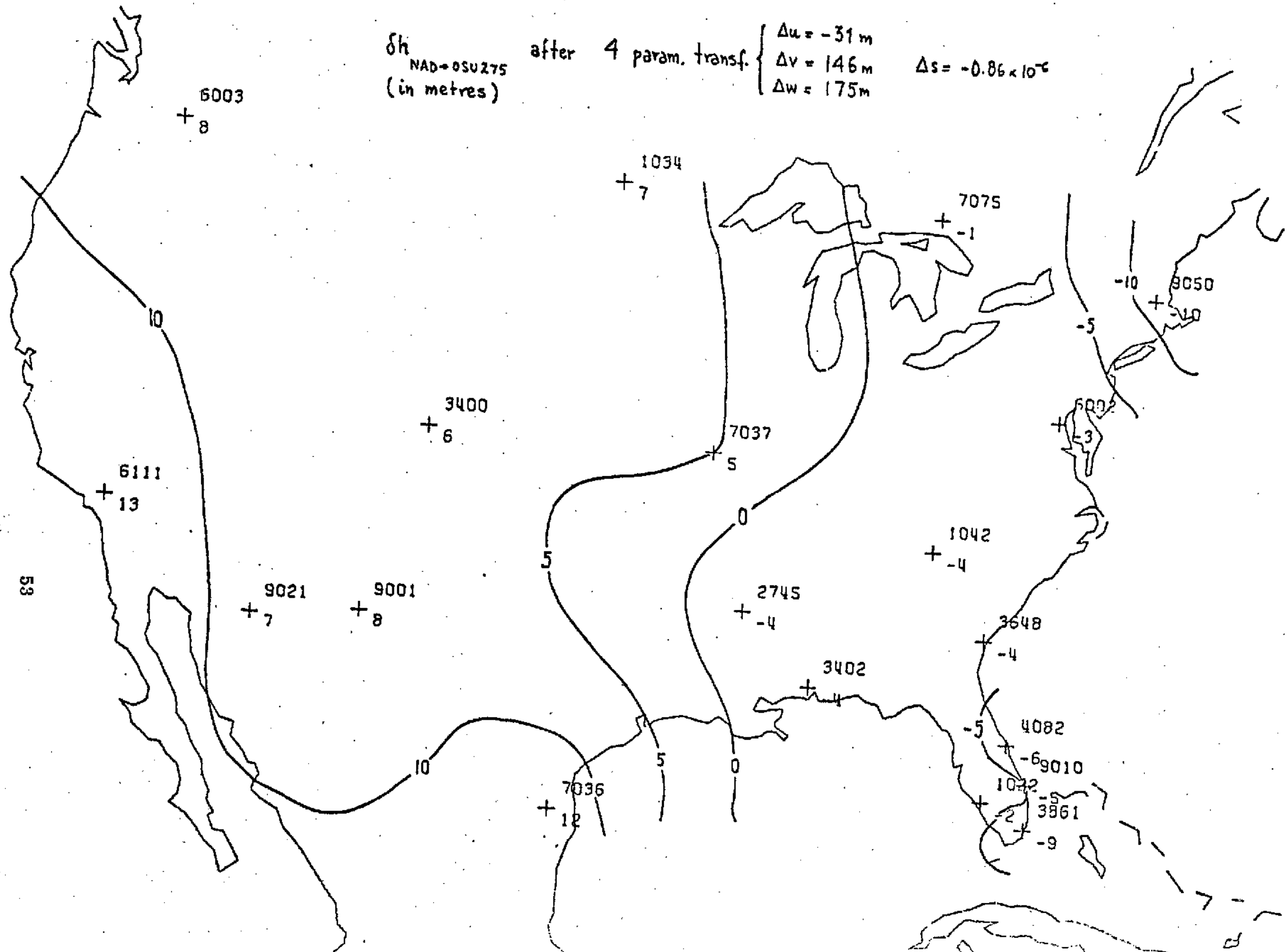
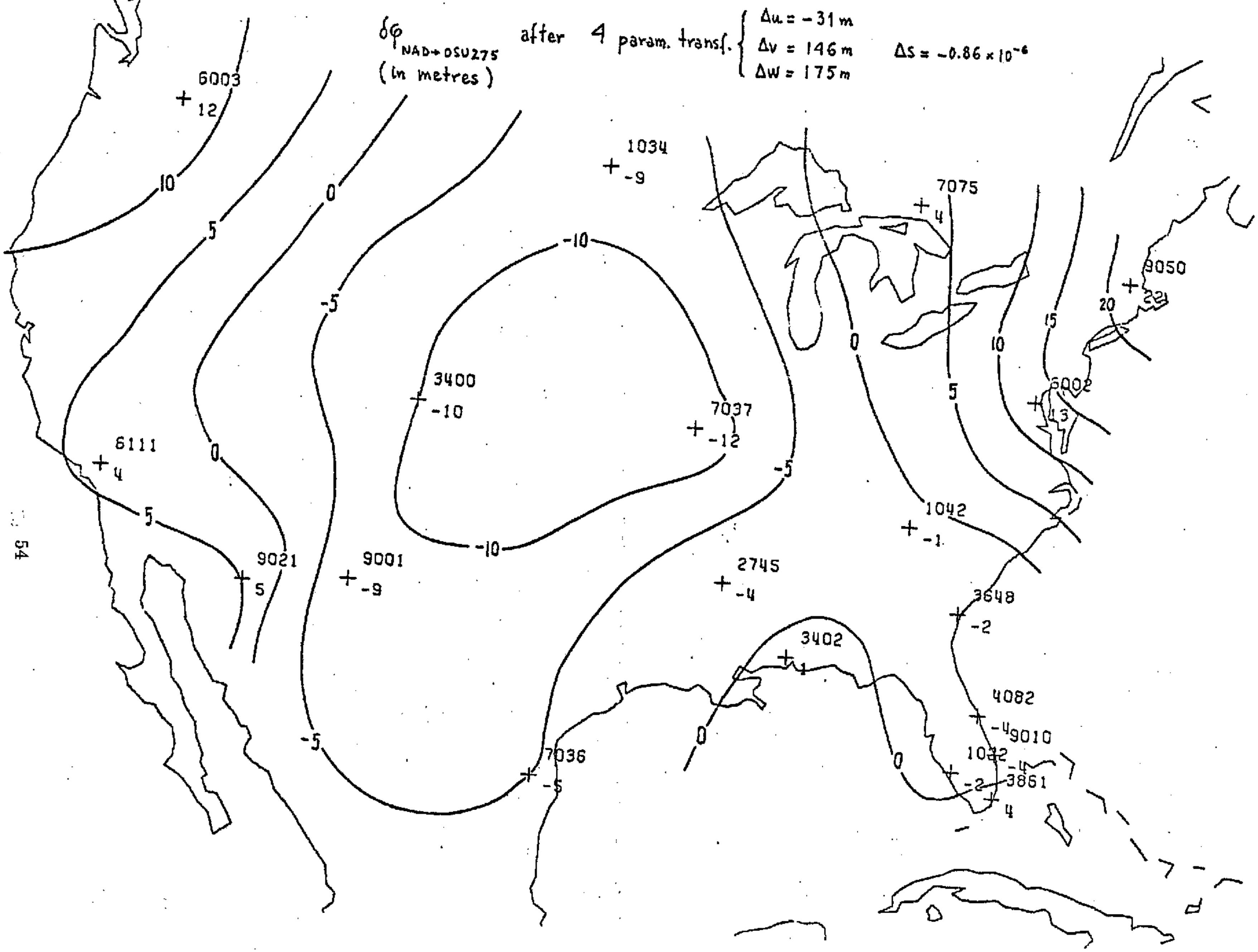


Fig. 2.3-4 Distortions of h in the NAD



2.4 Data Acquisition and Processing

Analysis of optical and laser data from the ISAGEX experiment, provided by CNES, is progressing slowly. Investigation is being made in two phases, the first using raw data as received from CNES, the second using preprocessed data. Examination is being made for suitability for both geometric and dynamic solution to determine whether further processing is justified. Examination indicates that in the area of Western Europe a geometric solution should be possible using optical observations only. These stations are given below:

Station Number	Station Name	Latitude	Longitude (E)
1072	Zvenigorod	55°41′	36°46′
1147	Ondrejov 2	49°55′	14°47′
1181	Potsdam	52°22′	13°03′
8009	Wippolder	52°00′	4°22′
8010	Zimmerwald	46°52′	07°27′
8011	Malvern	52°08′	358°01′
8019	Nice	43°43′	7°18′
8031	Early Point	55°44′	356°46′
8034	Ypburg	52°02′	4°21′
9004	San Fernando	36°27′	353°47′
9020	Dakar	14°46′	342°36′
9431	Riga	56°57′	24°03′
9432	Uzhgorod	48°38′	22°18′
9436	Naulakallio	60°14′	25°06′

Dynamic solutions are possible using combined data.

The optical data has been examined for simultaneity against a maximum time interval of 0.0002 sec, this being the maximum time discrepancy acceptable to the OSUGOP program. About 10% of the optical data provided will

be used in initial solutions (See Fig. 2.4-1). Suitable data has been prepared for examination using the USOGOP program (now know formally as GEOMSG). No simultaneous laser observations have been detected using the same criterion.

Preprocessing programs are being made available by Wolf Research and Development Corporation. It is expected that preprocessing will still cause considerable difficulties. The two phases of reduction will enable the effects of preprocessing to be examined in detail.

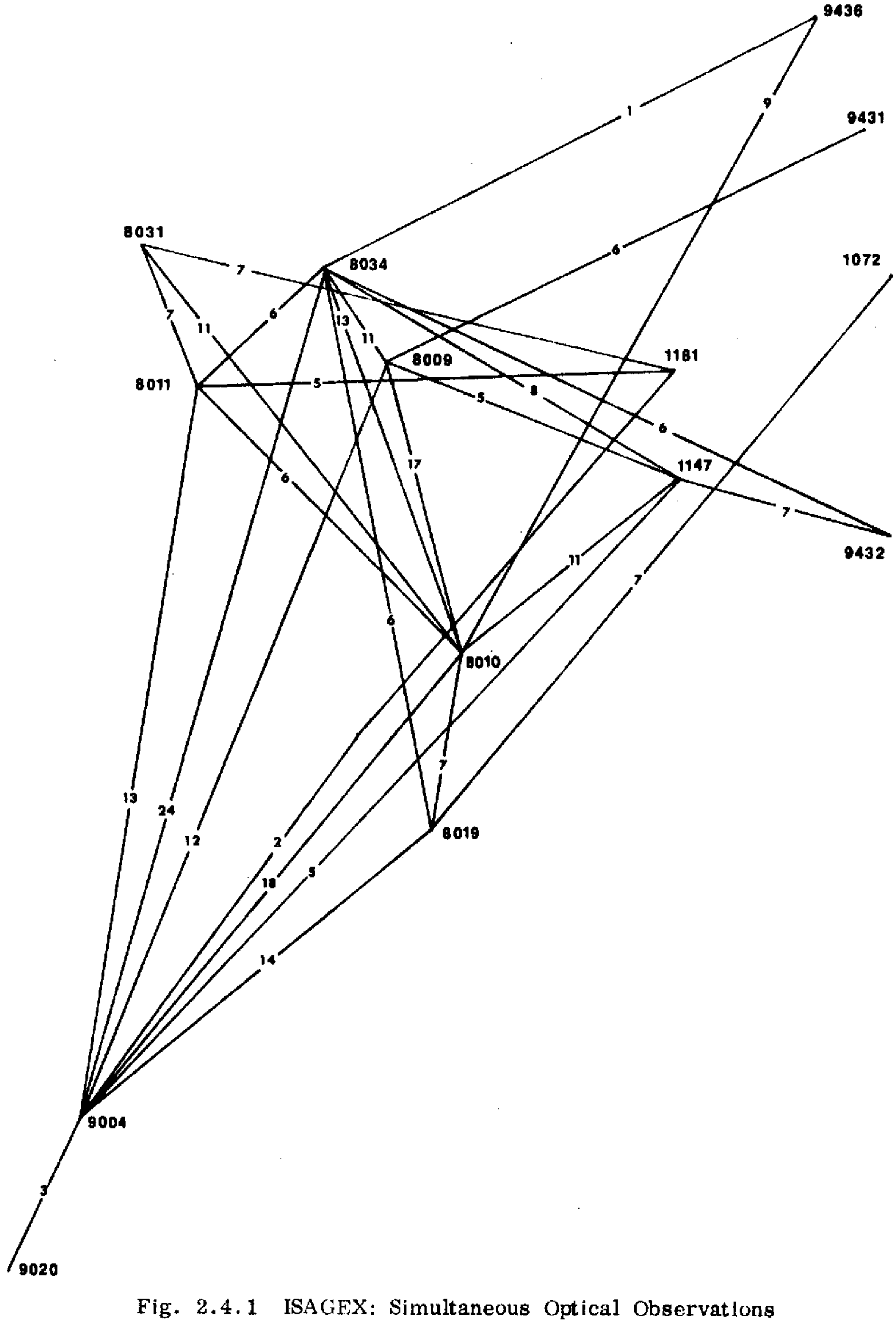


Fig. 2.4.1 ISAGEX: Simultaneous Optical Observations

3. ACTIVITIES RELATED TO EOPAP
(Contract No. NGR 36-008-204)

3.1 The LAGEOS Problem

3.11 Introduction

The Earth and Ocean Physics Applications Program (EOPAP) is an applications program based on the discipline of earth and ocean dynamics. Its primary goals are to identify, develop and demonstrate relevant space techniques that will contribute significantly to the development and validation of predictive models for earthquake hazard alleviation, ocean surface conditions, and ocean circulation.

In this program a passive stable satellite, LAGEOS, will be launched in 1976. The objectives of the LAGEOS program are to demonstrate the capability for making accurate determinations of the earth's crustal and rotational motions by means of laser satellite tracking techniques. This capability will be employed by observing:

-fault motion

-regional strain fields

-dilatancy

-tectonic plate motion

-polar motion

-earth rotation

-solid earth tides

-station positions

3.12 Statement of the Problem

Goal:

Accurate determination (cm-level) of points on the surface of the earth.

Means:

Range observations to a passive stable satellite.

Tools:

Laser pulse transmitter

Laser pulse receiver

Timing device

Satellite with reflectors

Statement of the Problem

A timing device measures the time ΔT a laser pulse (better: pulse train) needs to travel between the center of the laser pulse transmitter, the satellite reflectors and back to the laser pulse receiver.

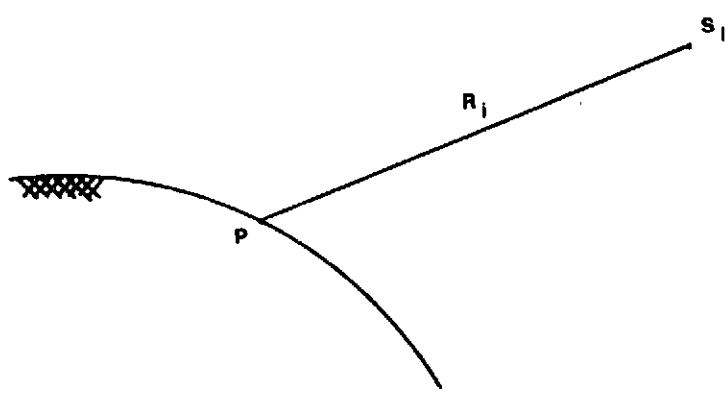


Fig. 3.-1-1

If we know the velocity V of the laser pulse we can compute the distance R_1 between the satellite and the observer

$$R_1 = \frac{V.\Delta T_1}{2} \tag{1}$$

If we also know the position of the satellite at a particular moment we are able to compute the position of the observer (x_p, y_p, z_p).

$$R_1^2 = (x_{s1}-x_p)^2 + (y_{s1}-y_p)^2 + (z_{s1}-z_p)^2 \tag{2}$$

We can consider equation (2) as the formula of a sphere with the satellite in its origin and the observer somewhere on its surface.

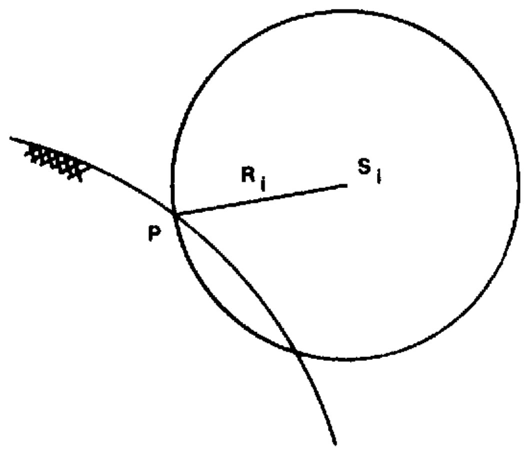


Fig. 3.1-2

If a second observation to the satellite is made, a second sphere has been established. The two intersecting spheres result in a circle on which the observer has to be located. A third observation will yield an adjustment. We have to note here that the three circles don't intersect in one point due to the shortcomings of mathematical modeling of physical realities.

In general two circles intersect in two points in two dimensional space and three spheres intersect in three circles in three dimensional space (provided that $r_1 - r_2 < M_1 M_2 < r_1 + r_2$ etc).

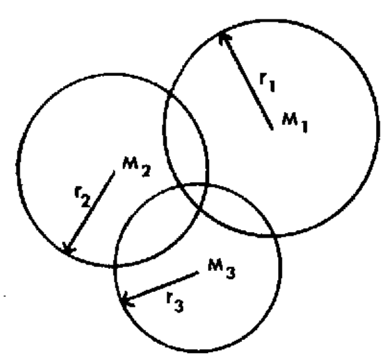


Fig. 3.1.3

Imagine that the observer is located at that point which is the closest to the three spherical surfaces.

Actually, a train pulse is transmitted

Fig. 3.1-4a

and received.

Fig. 3.1-4b

ΔT_1 refers to the best fit of the two signal trains.

Some numbers:

ex 1: $R_1 = 6000$ km $\rightarrow \Delta T_1 \simeq 0.04$ sec $= 40$ msec

ex 2: one way σ_1 cm $\sim \sigma_{0.03}$ nsec

two way σ_1 cm $\sim \sigma_{0.06}$ nsec

(1 nsec $= 10^{-9}$ sec)

ex 3: pulse train of 100 pulses

$\sigma_{\Delta T} = 0.1$ nsec

$\sigma_{R_1} = \dfrac{0.1}{\sqrt{100}} = \underline{0.01}$ nsec $= 0.15$ cm

3.13 Motions

Unfortunately the reduction of time to range is not that simple, due to different causes which can be summarized in one word MOTION.

Mobility of Transmitter and Receiver

To make observations possible in all directions the centers of the laser pulse transmitter T and the laser pulse receiver R may move with respect to a point P which we want to determine in position. The centers are those points where the actual time readings are made when the pulses pass.

Point P can be a benchmark, point on the mounting of the instrument etc.

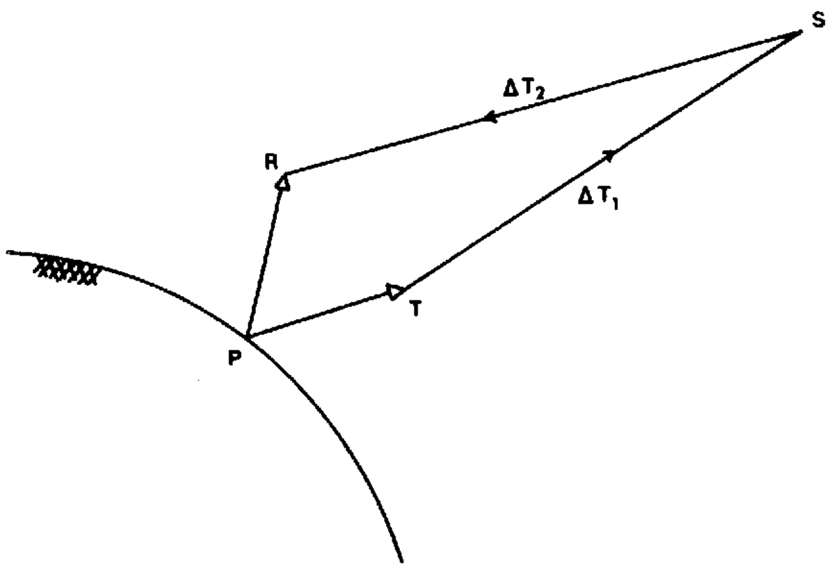


Fig. 3.1-5

When we speak about one observation, we have actually two: the time reading at T and R so that

$$\sigma^2_{\Delta T} = \sigma^2_{TT} + \sigma_{TR} \qquad (3)$$

The mobility of T and R means that for each observation the position of these two points with respect to A needs to be determined with an accuracy which should not destroy the accuracy of the range measurement. With proper instrumentation the requirements of accurate position determination of T and R can be met very easily.

Measurement:

$$\Delta T = \Delta T_1 + \Delta T_2$$

$$= \frac{R_{TS} + R_{SR}}{V}$$

$$= \frac{2R_{PS} + R_{TS} - R_{PS} + R_{SR} - R_{PS}}{V} \qquad (4)$$

If $\Delta R_1 = R_{TS} - R_{PS}$

and $\Delta R_2 = R_{SR} - R_{PS}$

then $$\Delta T = \frac{2R_{PS} + \Delta R_1 + \Delta R_2}{V} \qquad (5)$$

$$R_{PS} = \frac{V.\Delta T - \Delta R_1 - \Delta R_2}{2} \qquad (6)$$

whereby ΔR_1 and ΔR_2 has to be known with sufficient accuracy.

Rotation of the Earth

Even when T, R and P would coincide the reduction of ranges is not a simple affair because of the motion of point P during the observation due to the rotation of the earth.

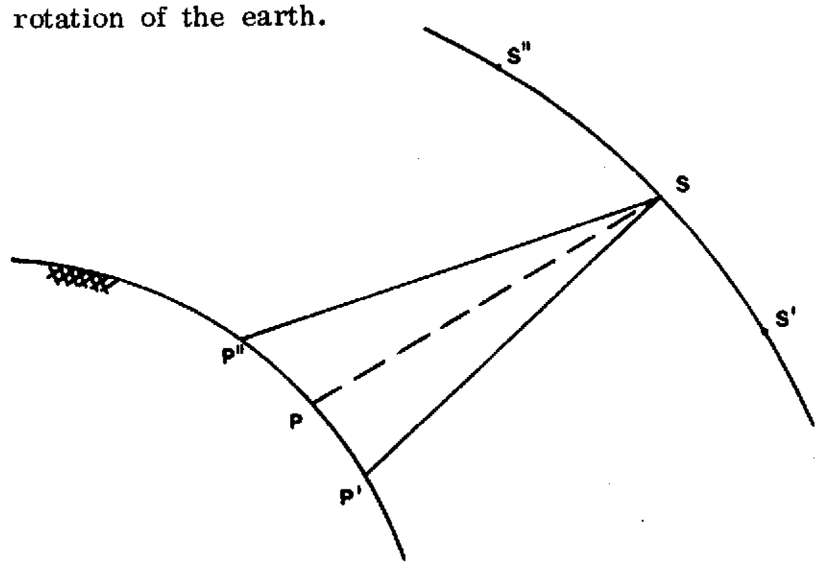


Fig. 3.1-6

For a satellite which is at a distance of 6000 km from P the laser pulse needs 0.04 sec travel time, as we have shown earlier. If point P is located at the equator (largest effect) it travels $0.04 \times \frac{40,000}{3600 \times 24} \simeq 0.02$ km =20 m during one observation!

If we want to refer the ranges to the moment of pulse arrival at the satellite we have to correct the "measured ranges".

Combining Figures 5 and 6 we get

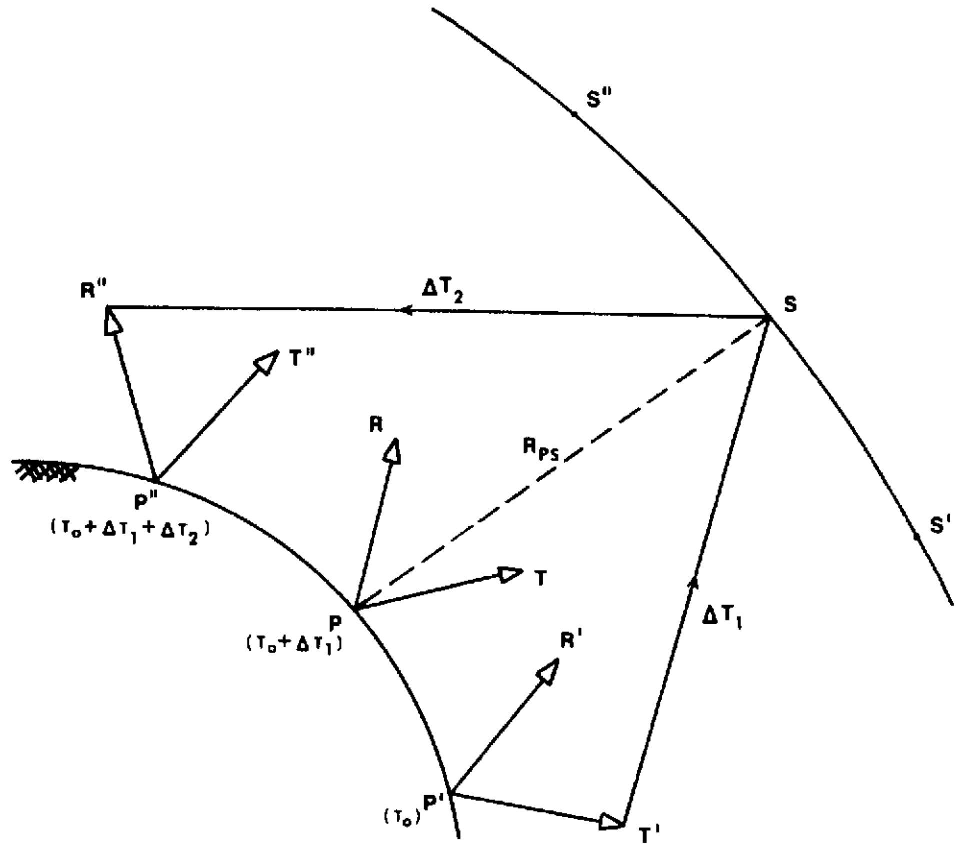


Fig. 3.1-7

$$\Delta T = \Delta T_1 + \Delta T_2$$

$$\begin{aligned} V.\Delta T &= R_{T's} + R_{SR''} \\ &= R_{P's} + \Delta R_1 + R_{SP''} + \Delta R_2 \qquad \text{(see previous chapter)} \\ &= 2R_{PS} + R_{P's} - R_{PS} + R_{SP''} + \Delta R_1 + \Delta R_2 \\ &= 2R_{PS} + \Delta R_1 + \Delta R_2 + \Delta R_3 + \Delta R_4 \qquad (7) \end{aligned}$$

where $\Delta R_3 = R_{P's} - R_{PS}$

and $\Delta R_4 = R_{SP''} - R_{PS}$

$$R_{PS} = \frac{V.\Delta T - \Delta R_1 - \Delta R_2 - \Delta R_3 - \Delta R_4}{2} \qquad (8)$$

whereby $\Delta R_1, \ldots, \Delta R_4$ has to be known with sufficient accuracy.

Refraction

Unfortunately, the velocity of light does depend on the medium it travels through. It means that the velocity will change in the different atmospheric layers. Furthermore, the light ray will not cross the atmospheric layers perpendicularly in general. This causes the light path to be curved so that

our computed range R_{PS} does not correspond to the shortest distance between point P and S.

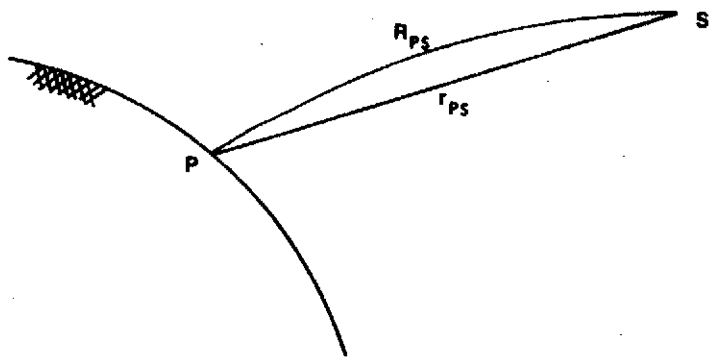


Fig. 3.1-8

We need the "measured" range R_{PS} to correct:

$$r_{PS} = R_{PS} - \Delta R_5 - \Delta R_6 \tag{9}$$

where ΔR_5 is the correction due to the varying velocity of light and ΔR_6 is the correction for the curvature of the light path.

It has been shown that the curvature effect (ΔR_6) is negligible above about 6° altitude. Therefore, only the retardation effect (ΔR_5) is taken into account.

Lasers having frequencies in the visible spectrum region are electomagnetic radiation which is hardly affected by the ionosphere and atmospheric water vapor. It is only affected in the troposphere and the stratosphere. Several refraction formulas are in use:

Thayer: $$\Delta R_{5_M} = \frac{2.238 + 0.0414\ (P_0/T_0) - 0.238\ H_0}{\sin E_0 + 10^{-3} \cot E_0} \tag{10}$$

where P_0: atmospheric pressure in millibars at observing station

T_0: temperature in °K at the observing station

H_0: laser's elevation above mean sea level in km

E_0: elevation of satellite

Saastamoinen: $\Delta R_{5M} = 0.002357 \sec Z\ (P_0 + 0.06 e_0 - B \tan^2 Z) + \Delta L$ (11)

where Z: apparent zenith distance of satellite

P_0: total pressure in millibars

E_0: partial pressure of water vapor in millibars

B, ΔL: quantities to be taken from tables

Other Error Sources and Summary

Other error sources are:

- the eccentricity of the point from which the laser pulse is reflected, with respect to the center of mass of the satellite
- calibration of the velocity of the laser pulses
- delays in the cables of the transmitter and receiver, etc.

If we collect these additional error sources in a term ΔR_6, we can give the following formula for the distance r_{PS} we are ultimately interested in:

$$r_{PS} = (V \cdot \Delta T - \sum_{i=1}^{4} \Delta R_i - 2\sum_{i=5}^{6} \Delta R_i)/2 \qquad (12)$$

The following expectations seem to be reasonable:

Tropospheric propagation velocity uncertainties	15 mm
Laser	
Pulse detection	10 mm
Range counter	5 mm
Cables, mechanical, calibration target survey, calibration propagation velocity, etc.	5 mm
Epoch (time synchronization)	5 mm
Satellite	5 mm
σr_{PS} =	20 mm

As we can see from this table 55% of the accuracy of the range observations will be determined by the tropospheric refraction. Consequently, the ultimate accuracy of laser ranging will depend on the accuracy of the refraction models mentioned earlier. Depending on the refraction

model no observations should be made outside a certain cone around the zenith axis.

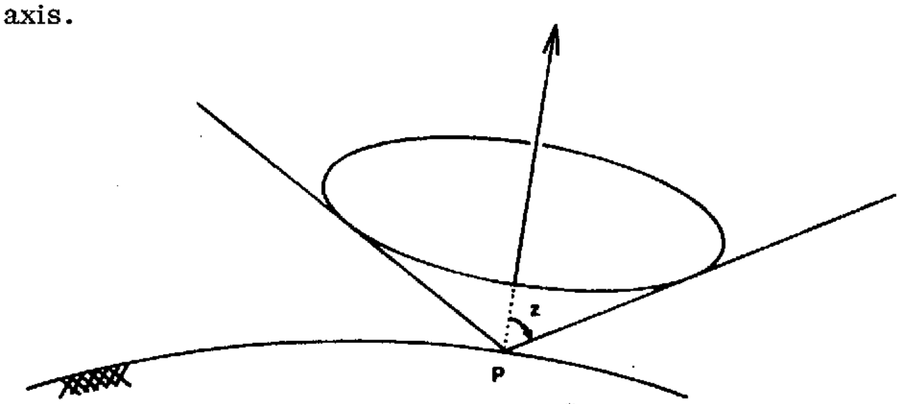


Fig. 3.1-9

A safe maximum zenith angle z of 75° is often being used.

A not too old estimate is that the refraction correction (ΔR_{6}) can be obtained with an accuracy which is equal to 1% of the total correction.

Needless to say that with refraction corrections from 2-6 meters, much research still needs to be done to obtain that (optimistic ?) expectation of 15 mm.

3.14 Ephemeris

Up to this point only the fact has been considered that we are able to recover earth fixed coordinates with high accuracy as long as we know the position of the satellite.

The orbit of the satellite will deviate from any ideal orbit (ellipse) due to

1. the irregularities of the earth's gravity field
2. solar pressure
3. earth shine
4. atmospheric drag
5. presence of other celestial bodies

Our knowledge of the quantities (better: the uncertainties of the quantities) which describe the different force models, will influence the accuracy with which we can generate satellite orbits, i.e. ephemeries.

3.14.1 Earth's Gravity Field

Even if we know the satellite's position at T_o (e.g. from simultaneous range observations) the accuracy with which we can compute its position at $T_o + \Delta T$ when the actual observation takes place ($\Delta T = 1$ hr, 24 hr.,... ?) will largely depend on our knowledge of the earth's gravity field.

A method to describe the earth's gravity field is the representation by spherical harmonics. Especially, the uncertainties of the spherical harmonic coefficients will propagate through into the uncertainty of the position of the satellite.

Others argue that discussions based on spherical harmonic representations are misleading (too pessimistic) in that sense that these coefficients and their standard deviations reflect the total gravity field rather than local gravity information above which the satellite flies at a particular moment.

Representations by gravity anomalies would more advantageous because they are available in large amount just in those areas where information about crust motions is needed. See further the remarks in section 3.15

<u>Geopotential Models</u>

The results of laser ranging to LAGEOS depend very much on the success of the mission by the SEASAT and GRAVSAT satellites. They have to provide more accurage geopotential models. Currently the resolution of satellite determined models is in the order of 1500 km ($m = \frac{40000}{2x1500} \simeq 15$). The wavelength is 3000 km but 1500 km features can be resolved so that

$$\text{order } (m) = \frac{40.000 \text{ km}}{2\text{xresolution}}$$

GRAVSAT is meant to provide a 200 km resolution (which means a system of $(\frac{40.000}{2x1500})^2 \simeq 10.000$ unknowns!)

A geopotential model of degree and order 100 and a 10 cm geoid are features which need to be accompanied by big question marks. The

fact that the potential field smooths out as the altitude increases, is a reason for high altitude satellites. Research needs to be done to find relations between altitude and degree/order of the potential coefficients needed to describe the potential field at those altitudes with such an accuracy that 5 cm ephemeries can be obtained.

<u>Resonance</u>

Two types of resonance can be recognized:

A. For orbits which have eccentricities and inclinations close to zero parameters as longitude of the ascending node Ω, argument of perigee ω and mean anomaly M start to lose their significance.

Due to this rather mathematical than physical phenomenon large perturbations in Ω, ω and M will finally cancel out in coordinate computations.

B. For orbits of satellites which have secular rates of Ω, $\dot{\omega}$, M, θ close to zero so that the periodic variation of these elements are more significant than the secular rates.

In general:

$$(l-2p)\,\dot{\omega} + (l-2p+q)\,\dot{M} + m\,(\dot{\Omega} - \theta) \approx 0 \tag{13}$$

<u>ex. 1</u>: $l-2p = 1$

$l-2p + q = 1$

$m = 1$

$$\dot{\omega} + \dot{M} + \dot{\Omega} - \dot{\theta} = 0 \tag{14}$$

note that q=0 and l-m=2p (i.e. l-m is even)

<u>ex. 2</u>: $l-2p = 1$

$l-2p + q = 1$

$$\dot{\omega} + \dot{M} - m\,(\dot{\Omega} - \dot{\theta}) = 0 \tag{15}$$

note that q = 0 and l-1 = 2p (i.e. l is odd)

Kepler's law: $n^2a^3 = k^2M$ (16)

$$a = \left(\frac{k^2M}{n^2}\right)^{1/3} \tag{17}$$

Resonance occurs for those satellites for which the mean motion n is equal to m (order) times the rate of rotation of the earth:

$$n = m.\omega \tag{18}$$

Inserting in equation 17 gives:

$$a = \left(\frac{k^2 M}{m^2 \omega^2}\right)^{1/3} \approx \left(\frac{17}{m}\right)^{2/3} a_e$$

or

$$m = 17 \left(\frac{a_e}{a}\right)^{3/2} \tag{19}$$

For a satellite of altitude 9000 km we find:

$$m = 17 \left(\frac{6370}{6370 + 9000}\right)^{3/2} = 4.55$$

Orbits with altitudes between 5000 and 6500 km have mean motions (revolutions per day) between 6 and 7.

Correspondingly, mean motions of 6, 7 are resonant with 6th and 7th order coefficients respectively.

The altitude which minimizes resonant effects of both the 6th and 7th order coefficients is around 5900 km for orbits with inclinations of 110°.

The investigation of resonant effects has to be seen in the following light.

Representation of the earth's gravity field by spherical harmonics is one of the many possible representations: gravity, anomalies, mass points, etc.

The spherical harmonic representation involves coefficients of certain degree (l) and order (m); l and m are integers.

As said earlier some resonant effects will depend on the order of potential coefficients. A satellite with mean motion m (i.e. m revolutions a day) is resonant with the m-th order potential coefficients. That is why it is suggested to avoid satellite altitudes of 5000 km (7 revolutions a day) or altitudes of 6500 km (6 revolutions a day), etc.

From this discussion we can see that nothing else than the value of integers excludes certain altitudes, which is as unsatisfactory as the method of spherical harmonics itself. As explained in section 4.1.1, 5 cm ephemeries are needed which can only be obtained by very accurate geopotential models. Accurate description of these models by spherical harmonics require astronomical amounts of unknowns. For instance, a geopotential model that has a resolution of a half wave length of 20 km needs $\left(\frac{40.000}{2x20}\right)^2 \simeq 1$ million potential coefficients; in other words, we have to solve (adjust) systems with that same huge amount of unknowns.

As the observations get progressively more accurate continuation of the use of spherical harmonics in the future is perhaps as foolish as the man who tries to describe a neat mathematical curve as the parabola is, $y = a_2x^2+a_1x+a_0$ (3 unknowns) by Fourier series, $y = 1/2\ a_0 + \sum_{m=1}^{n} (a_m \sin m\lambda + bm \cos m\lambda) + E$, i.e. $(n^2 + 1)$ unknowns for $E<10^{-p}$.

Needless to say that in my opinion for altitude considerations very low weight should be given to reasons of resonance because it is the result of shortcomings of spherical harmonics technique, which use has at least to be questioned in future geodesy.

It has to be noted that resonant effects can play an important role in the cases where they may shorten the lifetime of a satellite with considerable time.

The useful life of LAGEOS is estimated as 20 years.

3.14.2 Solar Pressure

Direct solar photon pressure will produce orbital perturbations with a period equal to that of the orbit.

At an altitude of 3700 km it causes accelerations of $120x10^{-9}$ cm/sec^3 (force = 0.084 dyne). Due to its well known characteristics perturbations can be computed to better than 1 cm.

However, increasing the altitude to 9000 km will cause the perturbations to increase with a factor of 120 ! , due to:

a. trackibility: the size of the satellite has to be increased for higher altitudes

b. limitations of the Delta launch vehicle: the mass of the satellite has to be decreased for higher altitudes.

The result of both effects is a less dense satellite which will cause higher increases of perturbations than one would expect (factor 120).

3.14.3 Earth Shine

Unlike direct solar radiation, earthshine is variable in magnitude and roughly constant in direction relative to the satellite velocity vector. Consequently, the effects on the orbit do not balance out (as solar photon pressure does in case of near-circular orbits) but tend to be cumulative. The light reflected by the earth and its thermal radiation will exert forces that will vary in both intensity and direction as a function of time and geography (cloud coverage, etc.).

At an altitude of 3700 km it causes accelerations up to 30×10^{-9} cm/sec^2 (variable force up to 0.02 dyne). Perturbations produced by earthshine can be as large as 40 cm after 24 hours. If the required accuracy is 5 cm for 24 hr arcs, we need

a. a high mass-to-area ratio, which is limited by the capabilities of the Delta bunch vehicle

b. a large altitude increase, which is also limited by the Delta bunch vehicle if we want to maintain a constant mass-to-area ratio

c. accurate cloud-cover data from meteorological satellite observations.

Increasing the altitude to 9000 km will cause the perturbations to increase with a factor of 15.

3.14.4 Atmospheric Drag

At an altitude of 3700 km atmospheric drag causes accelerations of 0.01-0.4 x 10^{-9} cm/sec^2 which is negligible small (force=1-40x10^{-6} dyne). Higher altitudes will only decrease the effect of atmospheric drag.

3.14.5 Micrometeorites and other celestial bodies

At an altitude of 3700 km impacts of micrometeorites causes accelerations of 0.004x10^{-9} cm/sec^2 which is negligible small (force=2.4x10^{-6}dyne).

The ephemeries of sun/moon/planets are well enough known to compute their influence on earth satellite with high accuracy.

3.15 Arc Range Measurements (Short Arc Method) and Accuracy Estimates

Basically two methods are available:

a. Simultaneous range measurements which fall under the chapter of geometric satellite geodesy (see Thirteenth Semi-annual Status Report pp. 80-85)

b. Arc range measurements which fall under the chapter of dynamic satellite geodesy.

Short arc methods are more feasible because of the absence of simultaneous good weather requirements.

Despite its more realistic value this method has a disadvantage because the model is not only described by parameters as station and satellite positions (the latter ones can be eliminated), but has also a large number of additional parameters.

In cases of the short arc methods these extra parameters are mainly the potential coefficients of the earth's gravity field and the orbital parameters.

Due to uncertainty of these additional parameters we expect to obtain lower accuracies for the station coordinates than those obtained by simultaneous laser range measurements.

A study has been conducted of the influence of the altitude of the satellite on station coordinates in the case of arc range measurements.

The result of this study follow below:

<u>Accuracy Obtainable from Range Arc Observations to Satellites</u>

Measurements:	Ranges to satellite r_i
Unknowns:	Station coordinates X_P, Y_P, Z_P
Knowns:	Satellite coordinates $X_{S\,i}$, $Y_{S\,i}$, $Z_{S\,i}$
Model:	$(X_P - X_{S\,i})^2 + (Y_P - Y_{S\,i})^2 + (Z_P - Z_{S\,i})^2 = r_i^2$
Point of Interest:	Var/Covar Matrix of station coordinates X, Y, Z → U, V, W where U: radial V: longitudinal **W**: latitudinal
Assumptions:	A. Rotational symmetric gravity field $\rightarrow e = 0 \rightarrow \Sigma\vec{X}_{S\,i} = 0$ B. Var/Covar Matrix of observations is unit matrix $\rightarrow \Sigma_{R\,i} = E \rightarrow$ var/covar matrix of station coordinates gives relative standard deviations (var.'s and covar.'s). C. only those arcs are considered which give the best relative standard deviation in either radial (u), longitudinal (v) or latitudinal direction. D. The observations are made with constant intervals (5sec) as long as the satellite was within the "observable cone" (max. zenith angle of 75^0).
Purpose of case study:	Which altitudes of the satellite yields the best relative standard deviations for the station coordinates.

Case I. Inclination of 90° (Polar Orbit)

Heights: 3750 km
5625 km
7500 km

Conclusions:

	S_U	S_V	S_W
3750 km	0.068	0.747-0.071	0.127-0.071
5625 km	0.055	0.605-0.058	0.121-0.059
7500 km	0.046	0.522-0.051	0.122-0.051

U: All stations can be determined with equal high accuracy in radial direction (there is always an orbit which passes the zenith)

V: The accuracies in longitudinal direction depend very much on:

a) The latitude of the station: the lower the latitude the worse, eg. H=3750 km $\rightarrow 0.071 < S_V < 0.747$ which is a variation up to 90%!

b) the height of the satellite: The higher the satellite the better, eg. H=3750 km $S_V = 0.557$ for $\varphi = 45^{\circ}$
H=7500 km $S_V = 0.139$

which is an improvement of 75%!

W: All stations can be determined with almost equal high accuracy in latitudinal direction

To improve the situation in longitudinal direction the orbit of the satellite is given a certain inclination (110°).

CaseII: Inclination of 110° (Retrograde)

Heights: 3750 km
5625 km
7500 km

Conclusions:

	S_U	S_V	S_W
3750 km	0.068-1.366	0.656-0.076	0.357-0.089
5625 km	0.055-1.890	0.513.0.060	0.307-0.067
7500 km	0.046-3.511	0.423-0.052	0.280-0.051

U: Giving the satellite other than polar orbits will yield limitations for the latitude of stations from which the satellite can be observed→the higher the satellite the greater the loss in accuracy for stations in polar regions→eg. H=7500 km & S_U, S_V, S_W < 0.425 will yield $\varphi_{MAX}=80^0$ (see graphs)

V: Although the depencency on latitude and height doesn't disappear, the inclination of 110^0 gives an improvement of about 20%.

W: Although the accuracy is worsened for stations around the equator, the accuracy of the latitudinal component stays well within the limits mainly determined by the longitudinal and radial (max. latitude) components.

Remark: Assumption A turns out to be not too harmful because the irregularities (better: the uncertainties in the irregularities) of the gravity field can only amplify the general conclusion of this study: The higher the better.

90°	3750			5625			7500		
	U	V	W	U	V	W	U	V	W
0	0.0676	0.7466	0.1273	0.0541	0.6045	0.1213	0.0459	0.5217	0.1222
	0.2720			0.1170			0.0465		
15	0.0676	0.6822	0.0709	0.0541	0.5297	0.0582	0.0458	0.4344	0.0508
	0.1026			0.0549			0.0520		
30	0.0675	0.6235	0.0690	0.0540	0.4645	0.0602	0.0457	0.3677	0.0511
	0.0683			0.0540			0.0458		
45	0.0674	0.5566	0.0677	0.0539	0.3895	0.0582	0.0456	0.1390	0.0502
	0.0675			0.0546			0.0457		
60	0.0673	0.1410	0.0705	0.0538	0.0806	0.0581	0.0455	0.0804	0.0503
	0.0700			0.0539			0.0455		
75	0.0673	0.0784	0.0707	0.0537	0.0676	0.0587	0.0454	0.0509	0.0509
	0.0675			0.0538			0.0454		
90	0.0672	0.0711	0.0713	0.0537	0.0584	0.0588	0.0454	0.0506	0.0512
	0.0805			0.0643			0.0544		

110°	3750			5625			7500		
	U	V	W	U	V	W	U	V	W
0	0.0689	0.6558	0.3565	0.0554	0.5128	0.3072	0.0472	0.4233	0.2798
	0.1921			0.1149			0.0924		
15	0.0689	0.5719	0.0956	0.0554	0.4245	0.1262	0.0472	0.3326	0.1339
	0.0957			0.0555			0.0522		
30	0.0689	0.4621	0.0684	0.0553	0.2465	0.0991	0.0471	0.1340	0.1015
	0.0690			0.0559			0.0483		
45	0.0688	0.1242	0.1499	0.0552	0.0869	0.1014	0.0470	0.0710	0.0796
	0.0695			0.0558			0.0470		
60	0.0687	0.0787	0.1076	0.0551	0.0643	0.0757	0.0469	0.0559	0.0508
	0.0689			0.0552			0.0469		
75	1.2873	0.0757	0.0929	0.2470	0.0602	0.0636	0.1049	0.0516	0.0541
85	1.3141	0.0796	0.0885	1.6036	0.0725	0.0660	0.8826	0.0532	0.0553
90	1.3660	0.0892	0.0895	1.8903	0.0662	0.0666	3.5112	0.0661	0.0619

From this study it becomes clear that for accurate radial determinations the satellite's zenith angle needs to be as small as possible whereas for accurate horizontal determinations the satellite needs to be as close as possible to the local horizon. In other words, horizontal control is best determined when the satellite is not above the region of interest, so that geopotential models based on gravity anomalies there do not necessarily prevail over models based on spherical harmonics. Only in the case of the accuracy of the radial component a too pessimistic figure may be obtained from the spherical harmonic coefficients.

In general, regarding LAGEOS, it seems that the big accuracy killers are:

a. refraction as far as the observations are concerned

b. earthshine (radiation pressure) and gravity field as far as the ephemeries is concerned.

Of course, the killers are related to the observational method being used:

1. simultaneous range observations

2. arc (short/long) range observations

Group 1 determines relative station positions. Only for this group can we talk about optimum satellite altitudes which influence the relative position of satellites (i.e. the accuracy of their separation) directly. See Aardoom's "Geometric Accuracy Obtainable from Simultaneous Range Measurements to Satellites" and "Thirteenth Semiannual Status Report, OSURF Project No. 2514.

<u>Advantage Group 1</u>

-killers of group b. don't play any roll

<u>Disadvantages Group 1</u>

-only very small percentage (<1%?) of observations can be used

- accuracy of station separation is very much altitude dependent

Group 2 determines absolute station positions. The accuracy of the

of the station determination is only altitude dependent in that sense that the higher the altitude the better the accuracy of the station positions.

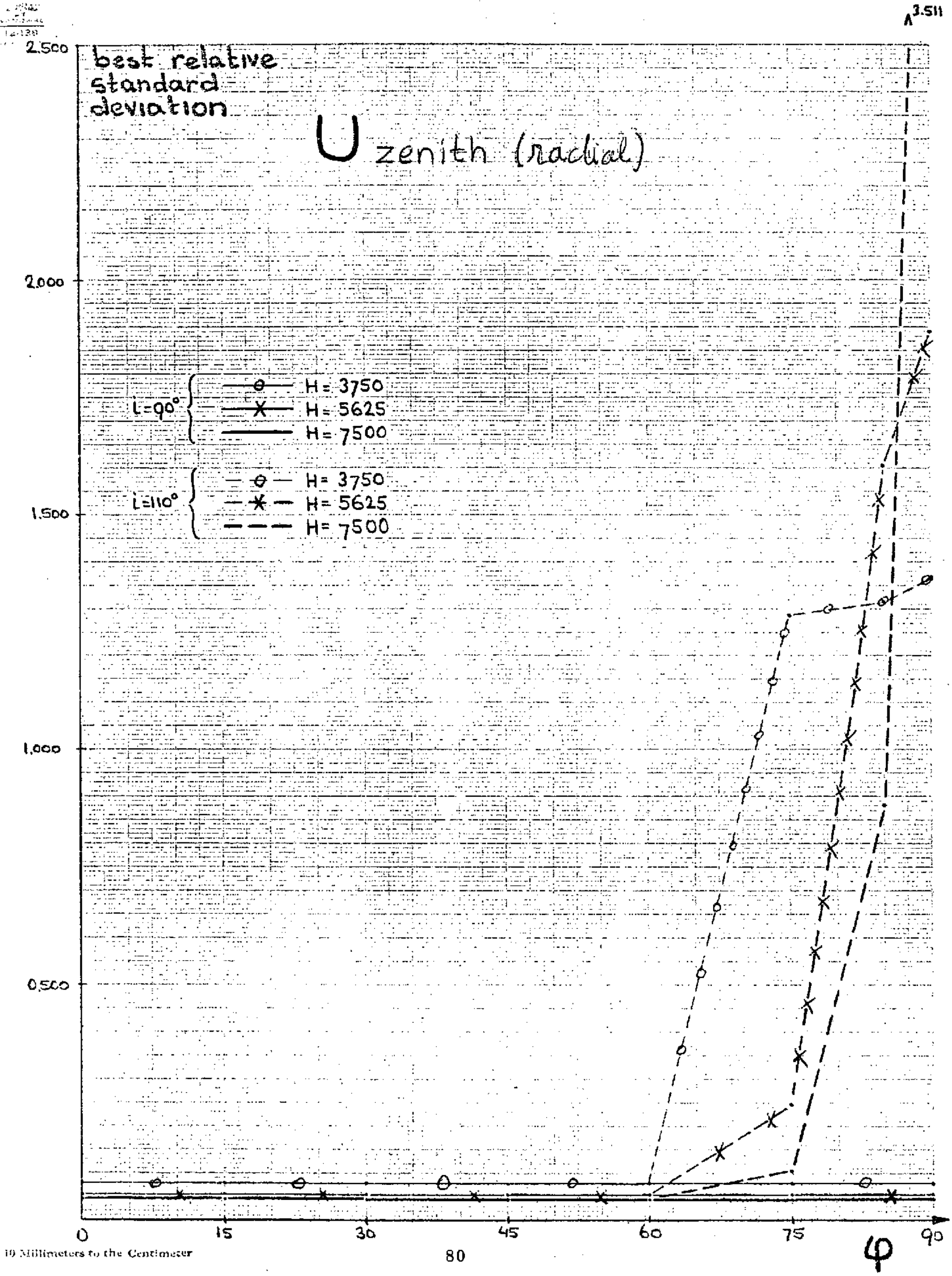
Advantage Group 2

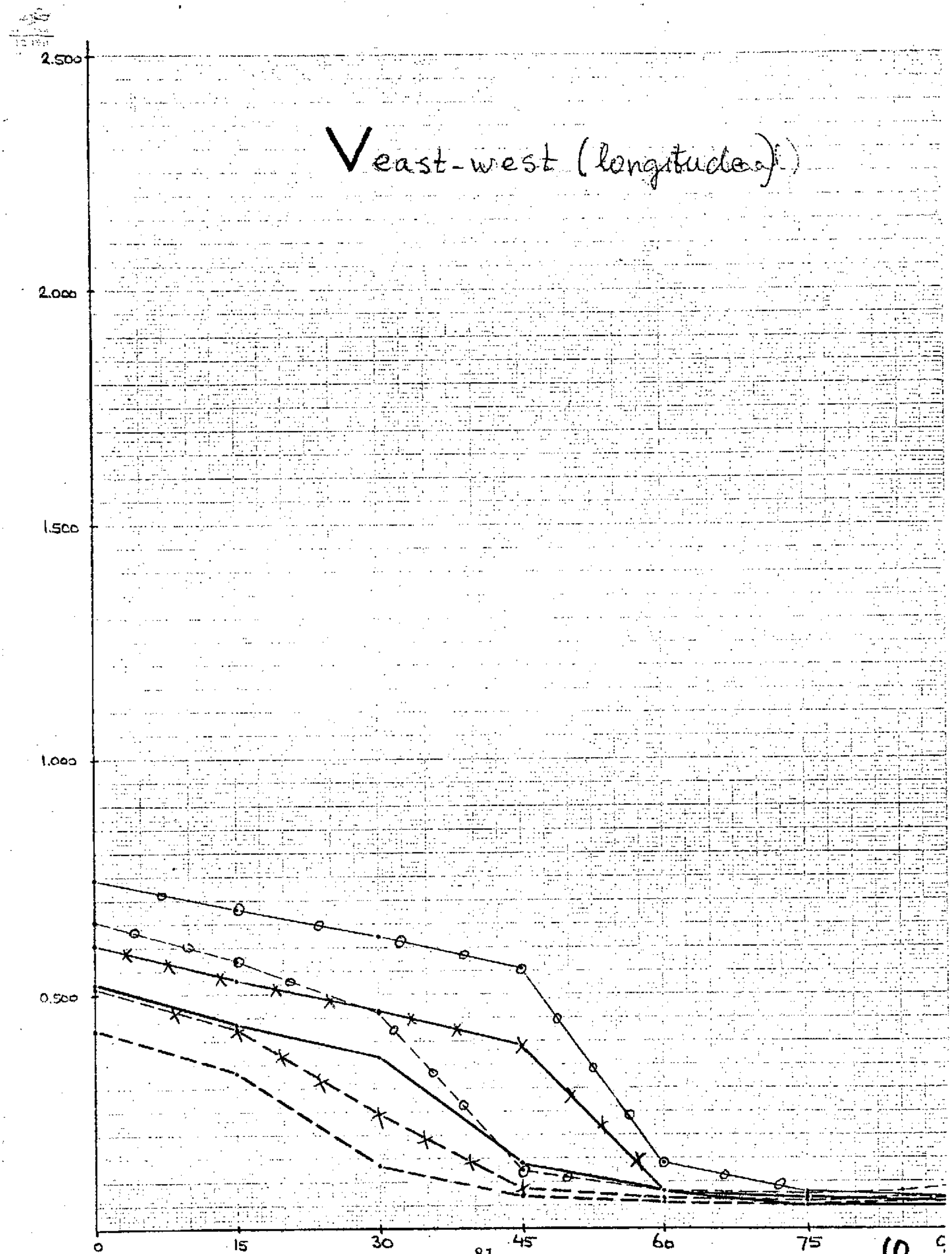
- all observations can be used

- the altitude determines the accuracy of the absolute positions of station which have only a favorable influence on the separation accuracy.

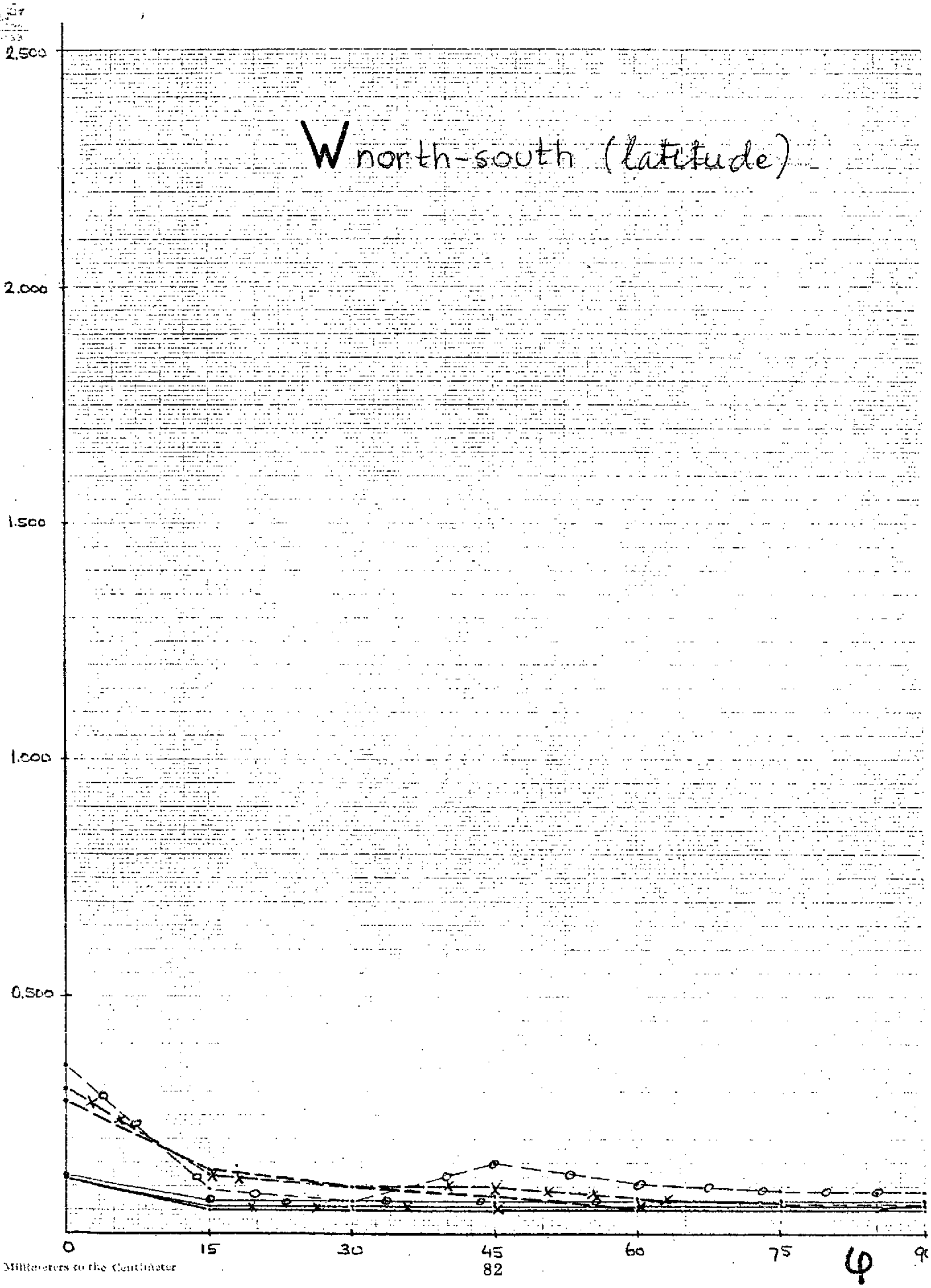
Disadvantages Group 2

-earthshine and gravity field can have an accuracy destroying influence (i.e., they influence the length of the arcs)


best relative standard deviation
U zenith (radial)
2,500
2,000
1,500
1,000
0,500
i=90°
H = 3750
H = 5625
H = 7500
i=110°
H = 3750
H = 5625
H = 7500
0
15
30
45
60
75
90
φ



10 Millimeters to the Centimeter



10 Millimeters to the Centimeter

3.2 Marine Geodesy

During the current reporting period the basic study of ocean physics applications (marine geodesy), reported in the last Semiannual Status Report, was further modified. This modification was done by soliciting comments on this study from scientists of other organizations who are involved with specific problem areas. The final version of this study, which is still being modified and updated, will be soon published under Reports of the Department of Geodetic Science.

A scientific cooperation between the Ohio State University (OSU) and Battelle Columbus Laboratories was also achieved during this reporting period. Since its first meeting on May 8, 1974 at OSU, the OSU-Battelle group met four times. The basic task of this cooperative team is to establish and to reconfirm the requirements, both scientific and practical (users' needs). To achieve this a questionnaire was given to the participants of the International Symposium on Applications of Marine Geodesy, Battelle Auditorium, Columbus, Ohio, June 3-5, 1974. The evaluation of the responses to the questionnaire was sent to the participants for their further information and comments (see enclosures on the next two pages).

Battelle
Columbus Laboratories

THE OHIO STATE UNIVERSITY

June 14 , 1974

Dear Colleague:

We would like to thank you for your assistance during the recent symposium on marine geodesy in Columbus, in filling out the questionnaire on your areas of interest. A summary of the responses is attached, so you can get some impression of the distribution of interest indicated by the others who responded. We received completed questionnaires from about half those attending the conference, so the results here should be reasonably indicative of the interest of the entire group.

As you may recall, Battelle and the Ohio State University are engaged in a joint study of the requirements placed on marine geodesy by current and possible future applications. The questionnaires which you and the others at the conference filled out, and the Monday evening discussion session were most helpful to us, as were a number of individual conversations we had with those attending the meeting.

In view of the importance of clarifying and documenting the current and future requirements in marine geodesy for the scientific and engineering community, we would appreciate receiving at this time, your specific thoughts and comments.

Please direct your reply to Professor Mueller at the address below before August 1, 1974, if possible.

Sincerely,

Ivan I. Mueller

Ivan I. Mueller
Ohio State University

A. George Mourad

A. George Mourad
Battelle Columbus Laboratories

Department of Geodetic Science / 1958 Neil Avenue / Columbus, Ohio 43210 / Phone (614) 422-6753

Distribution of interests as indicated by responses to the Questionnaire

Application Areas		No.
1.	Navigation	
1.1	General Navigation (Long Range)	29
1.2	Submersible Navigation (Long Range)	17
1.3	Submersible Navigation (Short Range)	20
1.4	Navigation Instrumentation	23
2.	Ocean Resources	
2.1	Geophysical Surveys (Continental Shelf or Open Ocean)	24
2.2	Drilling	6
2.3	Pipe Lines	4
2.4	Cable Laying	2
2.5	Dredging and Mining	8
3.	Geodesy and Ocean Physics	
3.1	Charting	19
3.2	Mapping of the Ocean (Bottom)	26
3.3	Control Stations and Datum Definition	29
3.4	Geoid, Deflection of the Vertical, Gravity Anomalies, etc.	36
3.5	Calibration Standards, Ground Truth, Test Ranges, etc	21
3.6	Mean Sea Level, Altimetry, Leveling, etc	31
3.7	Buoy Location	13
3.8	Boundary Demarcation and Determination	20
4.	Ecology; Garbage Dump Sites; "New Land" Acquisition	3
5.	Search and Rescue; Recovery of Submerged Instrumentation and Objects	12
6.	Tsunami	3

4. PERSONNEL

Ivan I. Mueller, Project Supervisor, part time

Daniel McLuskey, Graduate Research Associate, from 10/1/73

Narendra K. Saxena, Research Associate, full time

Tomas Soler, Graduate Research Associate, part time

Muneendra Kumar, Graduate Research Associate, without compensation

5. TRAVEL

Mueller, Ivan I.
Washington, D.C. January 30 - February 1, 1974
To attend workshop on Mean Sea Level at NGS/NOAA

Mueller, Ivan I.
New Brunswick, Canada May 19 - 25, 1974
International Symposium on the Readjustment of the North American Datum

Mueller, Ivan I.
Columbus, Ohio June 3 - 5, 1974
International Symposium on Marine Geodesy, Battelle, Columbus, Ohio

Mueller, Ivan I.
Sao Paolo, Brazil; Mexico City, Mexico June 15 - July 12, 1974
To attend the 17th Planetary meeting of COSPAR, Sao Paolo, Brazil
To attend the first Pan American Congress on Geodesy, Mexico City, Mexico

Saxena, N. K.
LaJolla, California February 5, 1974
Discussions at Scripps Oceanographic Institute with Mr. Peter F. Worcester and at IGPP with Drs. Myrl Hendershott and Bernard D. Zetler (see Appendix)

Saxena, N. K.
Pasadena, California February 7, 1974
Discussions at JPL with Drs. Charles Elachi and Alwin W. Newberry, and at Tetra Tech. with Dr. Li-San Hwang

6. REPORTS PUBLISHED TO DATE

OSU Department of Geodetic Science Reports published under Grant No. NSR 36-008-003:

70 The Determination and Distribution of Precise Time
by Hans D. Preuss
April, 1966

71 Proposed Optical Network for the National Geodetic Satellite Program
by Ivan I. Mueller
May, 1966

82 Preprocessing Optical Satellite Observations
by Frank D. Hotter
April, 1967

86 Least Squares Adjustment of Satellite Observations for Simultaneous Directions or Ranges, Part 1 of 3: Formulation of Equations
by Edward J. Krakiwsky and Allen J. Pope
September, 1967

87 Least Squares Adjustment of Satellite Observations for Simultaneous Directions or Ranges, Part 2 of 3: Computer Programs
by Edward J. Krakiwsky, George Blaha, Jack M. Ferrier
August, 1968

88 Least Squares Adjustment of Satellite Observations for Simultaneous Directions or Ranges, Part 3 of 3: Subroutines
by Edward J. Krakiwsky, Jack Ferrier, James P. Reilly
December, 1967

93 Data Analysis in Connection with the National Geodetic Satellite Program
by Ivan I. Mueller
November, 1967

OSU Department of Geodetic Science Reports published under Grant No. NGR 36-008-093:

100 Preprocessing Electronic Satellite Observations
by Joseph Gross
March, 1968

106 Comparison of Astrometric and Photogrammetric Plate Reduction Techniques for a Wild BC-4 Camera
by Daniel H. Hornbarger
March, 1968

110 Investigations into the Utilization of Passive Satellite Observational Data
by James P. Veach
June, 1968

114 Sequential Least Squares Adjustment of Satellite Triangulation and
Trilateration in Combination with Terrestrial Data
by Edward J. Krakiwsky
October, 1968

118 The Use of Short Arc Orbital Constraints in the Adjustment of Geodetic
Satellite Data
by Charles R. Schwarz
December, 1968

125 The North American Datum in View of GEOS I Observations
by Ivan I. Mueller, James P. Reilly, Charles R. Schwarz
June, 1969

139 Analysis of Latitude Observations for Crustal Movements
by M.G. Arur
June, 1970

140 SECOR Observations in the Pacific
by Ivan I. Mueller, James P. Reilly, Charles R. Schwarz, Georges Blaha
August, 1970

147 Gravity Field Refinement by Satellite to Satellite Doppler Tracking
by Charles R. Schwarz
December, 1970

148 Inner Adjustment Constraints with Emphasis on Range Observations
by Georges Blaha
January, 1971

150 Investigations of Critical Configurations for Fundamental Range Networks
by Georges Blaha
March, 1971

177 Improvement of a Geodetic Triangulation through Control-Points
Established by Means of Satellite or Precision Traversing
by Narendra K. Saxena
June, 1972

184 Coordinate Transformation by Minimizing Correlations Between Parameters
by Muneendra Kumar
July, 1972

185 On the Geometric Analysis and Adjustment of Optical Satellite Observations
by Emmanuel Tsimis
August, 1972

187 Geodetic Satellite Observations in North America (Solution NA-9)
by Ivan I. Mueller, J. P. Reilly and Tomas Soler
September, 1972

188 Free Adjustment of a Geometric Global Satellite Network (Solution MPS-7)
by Ivan I. Mueller and M. C. Whiting
October, 1972

190 The Ohio State University Geometric and Orbital (Adjustment) Program (OSUGOP) for Satellite Observations
by J. P. Reilly, C. R. Schwarz and M. C. Whiting
December, 1972

191 Critical Configurations (Determinantal Loci) for Range and Range-Difference Satellite Networks
by E. Tsimis
January, 1973

193 Free Geometric Adjustment of the DOC/DOD Cooperative Worldwide Geodetic Satellite (BC-4) Network
by Ivan I. Mueller, M. Kumar, J. Reilly and N. Saxena
February, 1973

195 Free Geometric Adjustment of the Secor Equatorial Network (Solution SECOR-27)
by Ivan I. Mueller, M. Kumar and Tomas Soler
February, 1973

196 Geometric Adjustment of the South American Satellite Densification (PC-1000) Network
by Ivan I. Mueller and M. Kumar
February, 1973

199 Global Satellite Triangulation and Trilateration for the National Geodetic Satellite Program (Solutions WN 12, 14 and 16)
by Ivan I. Mueller and M. Kumar, J. P. Reilly, N. Saxena, T. Soler
May, 1973

The following papers were presented at various professional meetings:

"Report on OSU participation in the NGSP"
47th Annual meeting of the AGU, Washington, D. C., April 1966

"Preprocessing Optical Satellite Observational Data"
3rd Meeting of the Western European Satellite Subcommission, IAG, Venice, Italy, May 1967.

"Global Satellite Triangulation and Trilateration"
XIVth General Assembly of the IUGG, Lucerne, Switzerland, September 1967, (Bulletin Geodesique, March 1968).

"Investigations in Connection with the Geometric Analysis of Geodetic Satellite Data"
GEOS Program Review Meeting, Washington, D.C., Dec. 1967.

"Comparison of Photogrammetric and Astrometric Data Reduction Results for the Wild BC-4 Camera"
Conference on Photographic Astrometric Technique, Tampa, Fla., March 1968.

"Geodetic Utilization of Satellite Photography"
7th National Fall Meeting, AGU, San Francisco, Cal., Dec. 1968.

"Analyzing Passive-Satellite Photography for Geodetic Applications"
4th Meeting of the Western European Satellite Subcommission, IAG, Paris, Feb. 1969.

"Sequential Least Squares Adjustment of Satellite Trilateration"
50th Annual Meeting of the AGU, Washington, D.C., April 1969.

"The North American Datum in View of GEOS-I Observations"
8th National Fall Meeting of the AGU, San Francisco, Cal., Dec. 1969 and GEOS-2 Review Meeting, Greenbelt, Md., June 1970 (Bulletin Geodesique, June 1970).

"Experiments with SECOR Observations on GEOS-I"
GEOS-2 Review Meeting, Greenbelt, Md., June 1970.

"Experiments with Wild BC-4 Photographic Plates"
GEOS-2 Review Meeting, Greenbelt, Md., June 1970.

"Experiments with the Use of Orbital Constraints in the Case of Satellite Trails on Wild BC-4 Photographic Plates"
GEOS-2 Review Meeting, Greenbelt, Md., June 1970.

"GEOS-I SECOR Observations in the Pacific (Solution SP-7)"
National Fall Meeting of the American Geophysical Union, San Francisco, California, December 7-10, 1970.

"Investigations of Critical Configurations for Fundamental Range Networks"
Symposium on the Use of Artificial Satellites for Geodesy, Washington, D.C., April 15-17, 1971.

"Gravity Field Refinement by Satellite to Satellite Doppler Tracking"
Symposium on the Use of Artificial Satellites for Geodesy, Washington, D.C., April 15-17, 1971.

"GEOS-I SECOR Observations in the Pacific (Solution SP-7)"
Symposium on the Use of Artificial Satellites for Geodesy, Washington, D.C., April 15-17, 1971.

"Separating the Secular Motion of the Pole from Continental Drift - Where and What to Observe?"
IAU Symposium No. 48, "Rotation of the Earth," Morioka, Japan, May 9-15, 1971.

"Geodetic Satellite Observations in North America (Solution NA-8)"
Annual Fall Meeting of the American Geophysical Union, San Francisco, California, December 6-9, 1971.

"Scaling the SAO-69 Geometric Solution with C-Band Radar Data (Solution SC 11)"
Annual Fall Meeting of the American Geophysical Union, San Francisco, California, December 6-9, 1971.

"The Impact of Computers on Surveying and Mapping"
Annual Meeting of the Permanent Committee, International Federation of Surveyors, Tel Aviv, Israel, May 1972.

"Investigations on a Possible Improvement of Terrestrial Triangulation by Means of Super-Control Points"
IAG International Symposium - Satellite and Terrestrial Triangulation, Graz, Austria, June, 1972.

"Free Adjustment of a Geometric Global Satellite Network (Solution MPS7)"
IAG International Symposium - Satellite and Terrestrial Triangulation, Graz, Austria, June, 1972.

"Conjugate Gradient Method (Cg-Method) for Geodetic Adjustments"
Annual Fall Meeting of the American Geophysical Union, San Francisco, California, December 3-6, 1972.

"Preliminary Results of the Global Satellite Triangulation Related to the NGSP"
Journees Luxembourgeoises de Geodynamique, Luxembourg, February 19-21, 1973.

"Present Status of Global Geometric Satellite Triangulation and Trilateration"
54th Annual Spring Meeting of the American Geophysical Union, Washington, D.C., April 16-20, 1973.

"Free Geometric Adjustment of the OSU/NGSP Global Network (Solution WN4)"
First International Symposium on the Use of Artificial Satellites for Geodesy and Geodynamics, Athens, Greece, May 14-21, 1973.

"Earth Parameters from Global Satellite Triangulation and Trilateration"
International Symposium on Earth's Gravitational Field and Secular Variations in Position, Sydney, Australia, November 26-30, 1973.

"Review of Problems Associated with Geodetic Datums"
International Symposium on Problems related to the Redefinition of North American Geodetic Networks, Fredericton, N.B., Canada, May 20-25, 1974.

"Marine Geodesy - Problem Areas and Solution Concepts"
International Symposium on Application of Marine Geodesy, Battelle Auditorium, Columbus, Ohio, June 3-5, 1974.

"Station Coordinates and Geodetic Datum Positions from the National Geodetic Satellite Program"
First Pan American Congress and the
Third National Congress of Photogrammetry, Photointerpretation and Geodesy, Mexico City, Mexico, July 7-12, 1974.

TRIP REPORT OF N. SAXENA

Summary of Discussions at Scripps, JPL and Tetra Tech.

The undersigned travelled to La Jolla, California for participating in the Sixth GEOP Research Conference, February 4-5, 1974, and for discussing certain basic questions related to Ocean Physics Applications Program. On February 5 discussions were held in La Jolla with Drs. Myrl Hendershott and Bernard D. Zetler of IGPP, and with Mr. Peter F. Worcester of Scripps Oceanographic Institute. On February 7 discussions were held in Pasadena with Drs. Charles Elachi and Alwin W. Newberry of JPL, and with Dr. Li-San Hwang of Tetra-Tech, Inc.

The summary of the discussions is given below:

Q.: In your discussions with Dr. Loomis, you mentioned that it had been the intent of the writers of the Williamstown Report that the stations on the ocean bottom form a global network with the fundamental purpose to tie the geophysical ocean surveys to this global ocean-bottom network. What should be the accuracy for the ocean bottom stations to meet your (oceangraphic) requirements?

Hendershott: Somewhere around ± 100 m or even ± 500 m would be my guess.

Q.: You mentioned earlier that if tsunami could be detected in the open ocean, it would be very valuable to the Tsunami Warning System (TWS), which is practically unsatisfactory as two-thirds or more of all tsunami warnings are false alarms. Do you still have the same views?

Zetler: Yes, I believe that the tsunami detection in the open ocean would be very valuable.

Q.: As the tsunami wave height in the open ocean is about 30 cm or so, it should be possible to measure it by the existing water-pressure sensors (similar to that of Munk). These water-pressure sensors are reported to be able to measure the change of water column height above them with an accuracy of ± 1 mm. Could you explain how these sensors are calibrated, and whether water column pressure measured above the sensor is of rectangular or conical water volume?

Zetler: These sensors could measure the change of water column height to this high accuracy. We have tested it here. Recently in an international experiment such sensors were inter-calibrated; the report of this experiment, still in the preliminary draft form, will be sent to you soon. The sensor measures the pressure of a water "cone" whose base-diameter on the ocean surface could be larger than 2 km for sensor depth of 4 km. Due to this large ocean surface, the usual ocean surface roughness evens out. Although these sensors can detect ± 1 mm height changes, the problem is how to bring this information from ocean bottom?

Q.: We are only interested to bring up the information regarding the water column height differences when an earthquake of 6.3 or larger magnitude occur. The sensor can be programmed (activated) to relay the height difference information either immediately after the occurence of an earthquake of a certain magnitude and/or when the height difference reaches a certain value. This information can be transmitted to a surface buoy using sonar waves from where it can be relayed to TWS center via satellite (probably stationary satellite). Do you consider this approach feasible? Does any research effort exist to solve this problem?

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Zetler: Your approach is feasible. As a matter of fact, Frank Snodgrass (IGPP) is working to develop a system to bring up the information from the ocean bottom. It is a pity that he can not be reached today for discussions. Also Gaylord Miller (NOAA, Honolulu) is working on similar problems in deep oceans. It will be worthwhile to visit the TWS Center in Honolulu and discuss with Miller, whose ideas come very close to yours.

Q.: As the harmless tsunami waves of the deep ocean can build up to destructive heights on the coast due to the near-coast ocean bottom topography (which includes the coastal slopes, continental shelves, the U- and V- shaped inlet etc.), will the additional ocean bottom transponders on the continental slope/continental shelf be significantly useful? What will be the affect of sedimentation on these transponders?

Zetler: Yes, it will be. There will not be much effect of sedimentation. In any case, these transponders in continental shelf area can be used with a tripod. The problem will not be sedimentation but whether these can remain undisturbed by fishing equipment. It will be useful to study the fishing methods in the coastal areas of interest.

Remarks: I summarized my views regarding the configuration of ocean-bottom transponders, their emplacement technique, the achievable accuracy of these transponders and problem areas which can be solved by them. After this summary, Zetler suggested to me to meet Walter Munk; for this meeting Zetler would contact Munk in the hospital. In the afternoon Zetler informed me that Munk sends his regrets as he is fully committed for the next two days, but suggested to meet Peter Worcester of his group. Zetler arranged a meeting with Worcester, who is working on the problem to determine (i) the velocity and direction of currents in SOFAR Layer, and (ii) the sound propagation in SOFAR. For this study the position of the buoy in SOFAR

layer should be known to ± 1 m accuracy (This is obviously relative positional accuracy.). Worcester agrees that this is possible only with the help of the ocean bottom control-net in that regional area. However this regional net should be connected to a geodetic datum if in the future similar experiments are to be conducted, so that the entire operation, which is performed in pieces, can be connected to a unified system.

On February 7, I had an appointment with Alden A. Loomis of JPL. Due to his sudden change of schedule, discussions were held with Charles Elachi and Alwin W. Newberry. Due to the nature of discussion related to underwater research, Newberry mentioned that these problems could be discussed only by Loomis, and suggested that Loomis will contact me soon after his return, and eventually make a stop in Columbus for discussions on his next eastbound trip.

Elachi, who is an applied physicist, mentioned that the ocean-bottom topography could be "mapped" probably by sonar holography. However, he could not elaborate his statement further.

In the afternoon of February 7 discussions were held with Li-San Hwang of Tetra Tech., who is involved with tsunami research and tsunami effect on coastal areas. According to Hwang, observation of tsunami in the deep ocean is of vital importance for understanding the tsunami behaviour (characteristics) as in coastal areas they are effected by bottom topography. He did agree that the pressure sensors could be used for precise measurements. Hwang is more concerned about the coastal area damage by tsunami, specially when in the continental shelf areas oil explorations and site search for Nuclear power plant at Diabra (West Coast) are conducted.

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